PB83-146795

Recomendations on a Shortz/Longz S02 Air Quality Model Methodology for the Tacoma Tideflats Area

H. E. Cramer Co., Inc.
Salt Lake City, UT

Prepared for

Environmental Protection Agency
Seattle, WA

Nov 82

U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA

(Please read instructions on the reverse before completing)

1. REPORT NO. EPA-910/9-82-090	2.	3. RECIPIENT'S ACCESSION NO. PB83 146795

4. TITLE AND SUBTITLE RECOMMENDATIONS ON A SHORTZ/LONGZ SO_2 AIR QUALITY MODEL METHODOLOGY FOR THE TACOMA TIDEFLATS AREA	5. REPORT DATE November 1982
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) J. F. Bowers, W. R. Hargraves and A. J. Anderson	8. PERFORMING ORGANIZATION REPORT NO. TR-82-146-01
9. PERFORMING ORGANIZATION NAME AND ADDRESS H. E. Cramer Company, Inc. P.O. Box 8049 Salt Lake City, Utah 84108	10. PROGRAM ELEMENT NO.
	11. CONTRACT/GRANT NO. Contract No. 68-02-2547 Task Order No. 4 (Mod. No. 4)
12. SPONSORING AGENCY NAME AND ADDRESS U. S. Environmental Protection Agency, Region 10 1200 Sixth Avenue Seattle, Washington 98101	13. TYPE OF REPORT AND PERIOD COVERED Final
	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

The primary purpose of the study described in this report was to develop a methodology for applying the SHORTZ/LONGZ complex terrain dispersion models to the existing and proposed SO_2 sources located within and adjacent to the Tacoma, Washington tideflats area. The major tasks of the study were to: (1) review the meteorological and air quality data available for the Tacoma area to determine the meteorological conditions associated with the highest observed SO_2 concentrations; (2) evaluate the performance of the SHORTZ and LONGZ models in the Tacoma area following procedures currently recommended by the U. S. Environmental Protection Agency (EPA); and (3) prepare a report specifying procedures for using the SHORTZ/LONGZ models in the Tacoma area, including source inputs, meteorological inputs and receptor arrays. Because of time and level-of-effort constraints for the completion of the study, it was not possible fully to complete all of Tasks (2) and (3). However, an interim procedure for the use of the SHORTZ/LONGZ models in the Tacoma area is presented along with recommendations for future work to accomplish these objectives.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air pollution Meteorology Sulfur Dioxide Turbulent Diffusion	Dispersion Modeling Tacoma, Washington Complex Terrain SHORTZ LONGZ	

18. DISTRIBUTION STATEMENT Release unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

PB83-146795

EPA-910/9-82-090

United States
Environmental Protection
Agency

Region 10
1200 Sixth Avenue
Seattle WA 98101

Alaska
Idaho
Oregon
Washington

November 1982

EPA

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REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

EPA-910/9-82-090
November 1982

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Prepared by

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EPA Contract No. 68-02-2547
Task Order No. 4
Modification No. 4

Project Officer

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SECTION 1
INTRODUCTION

1.1 BACKGROUND AND PURPOSE

The industrialized Tacoma, Washington tideflats area is one of the most pressing and challenging air quality modeling problems facing the U. S. Environmental Protection Agency (EPA) Region 10, the Washington State Department of Ecology (DOE) and the Puget Sound Air Pollution Control Agency (PSAPCA). The problem is pressing because the air quality impacts of a proposed new source and a proposed plant modification must be evaluated for compliance with the Prevention of Significant Deterioration (PSD) Regulations and the National, Washington State and Puget Sound Ambient Air Quality Standards. The problem is challenging because of the complexity of the topography and meteorology of the tideflats area and the wide variety of emissions characteristics for the sources located in the area. The only previous dispersion model analysis of the area that included a detailed model verification effort (Cramer, *et al*., 1976) considered all of the existing sources of sulfur dioxide (SO_2) emissions, but focused attention on the most significant SO_2 source--the ASARCO-Tacoma copper smelter. Based on the performance in the 1976 study of the SHORTZ/LONGZ dispersion models, EPA Region 10 considers the SHORTZ/LONGZ models to be the most appropriate of the generally available dispersion models for application to the Tacoma tideflats area. Modification No. 4 of Task No. 4 of EPA Contract No. 68-02-2547 directed the H. E. Cramer Company, Inc. to use the funds and time available under the contract in a continuation of the 1976 study with the focus on the tideflats sources.

The primary purpose of the study described in this report was to develop a SHORTZ/LONGZ dispersion model methodology for application to the existing and proposed SO_2 sources in the Tacoma tideflats area. The three major subtasks of the study were defined as follows:

1. Review the available air quality and meteorological data from the Tacoma area, analyze these data to determine the various meteorological conditions which lead to high measured ambient SO_2 concentrations and analyze the meteorological data to determine other possible meteorological conditions which may lead to high SO_2 levels.

2. Evaluate the performance of the SHORTZ/LONGZ computer models for periods determined in Subtask 1, using the August 1981 draft EPA report "Interim Procedures for Evaluation of Air Quality Models" as a guideline.

3. Prepare a report which details a modeling methodology using the SHORTZ/LONGZ air quality dispersion models. The purpose of the methodology is to estimate maximum SO_2 impacts in the industrial area of Tacoma, Washington. The document shall specify a procedure for use of the models which includes model inputs (sources, receptors, meteorology), model options, and an example of model output. The document shall also include the justification for the recommended procedure and results of the model performance evaluation. It is important that the worst-case meteorological conditions recommended by the contractor are adequate to estimate maximum SO_2 impacts for averaging periods of 24 hours, 3 hours, one hour, and 5 minutes. An averaging period of one year may also be of concern.

Because of the time and level-of-effort constraints for the completion of the work under Modification No. 4 to Task Order No. 4 of EPA Contract No. 68-02-2547, it was not possible fully to complete all of Subtasks 2 and 3. However, recommendations for future work to accomplish these objectives are presented in this report, and an interim SHORTZ/LONGZ model methodology is suggested.

1.2 DESCRIPTION OF THE SITE

Figure 1-1 is a topographic map of the Tacoma tideflats and adjacent areas. The tideflats comprise the area of flat terrain in the Puyallup River valley bounded on the west by the elevated terrain of the Tacoma peninsula, on the northwest by Commencement Bay, and on the north and east by the elevated terrain of Brown's Point. Terrain elevations above mean sea level range from about 3 meters in the tideflats to over 180 meters on Brown's Point and to over 120 meters on the Tacoma peninsula. The combination of elevated terrain surrounding the tideflats and the presence of the land-water interface tends to produce complex mesoscale meteorological circulations. Thus, the development of an appropriate dispersion model methodology for the existing and proposed SO_2 sources in the tideflats area is a challenging task.

The ASARCO copper smelter, which is located near the tip of the Tacoma peninsula, is the principal source of SO_2 emissions in the region. The location of the 172-meter ASARCO Main Stack is shown by the ◉ symbol in Figure 1-1. The ASARCO smelter currently uses a Meteorological Curtailment Program (MCP) to maintain the applicable ambient air quality standards for SO_2, which are discussed below in Section 1.3. (The MCP curtails SO_2 emissions whenever meteorological conditions conducive to the occurrence of high short-term ground-level concentrations occur or are anticipated.) Based on the results of our previous study of the ASARCO smelter (Cramer, et al., 1976) as well as the results of this study, the ASARCO smelter is primarily responsible for the SO_2 ambient air quality on the Tacoma peninsula. ASARCO emissions also affect SO_2 ambient air quality on Brown's Point and occasionally affect ambient air quality within the tideflats.

The existing SO_2 sources located within the tideflats are the St. Regis kraft mill, the U. S. Oil & Refining plant, the Kaiser aluminum plant, the Pennwalt plant and the Hooker Chemicals (Hooker Division of Occidental Chemical Corporation) plant. (Figure 1-1 does not show all of the buildings at the Kaiser plant because the most recent USGS map available

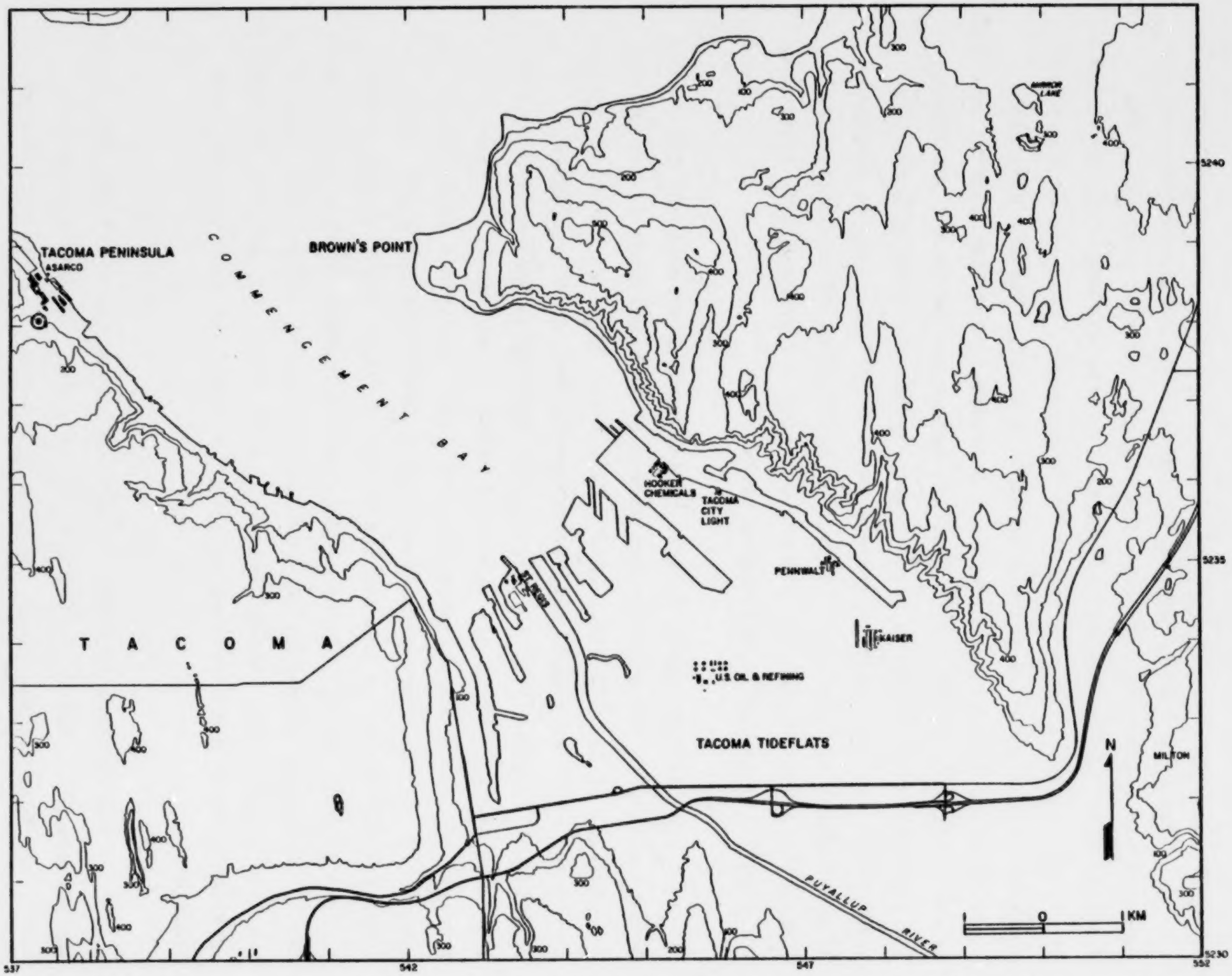

Figure 1-1. Topographic map of the Tacoma tideflats and adjacent areas. Elevations are in feet above mean sea level and the contour interval is 100 feet (30.5 meters). The ⊙ symbol shows the location of the ASARCO Main Stack.

for the area was updated in 1961.) The SO_2 emissions from the existing SO_2 sources in the tideflats are discharged from stacks which range in height from 12 meters (U. S. Oil & Refining flare stacks) to 81 meters (St. Regis Recovery Boiler No. 3). Additionally, SO_2 is contained in the slightly buoyant roof monitor emissions from the potlines at the Kaiser plant. Tacoma City Light proposes to build a cogeneration plant with a single 108-meter stack and it is our understanding that Kaiser is considering the use of an existing, but currently unused, 152-meter stack. Thus, the stack heights of potential concern for the sources within the tideflats range from 12 to 152 meters. These variations in emission heights and source types further complicate the development of an appropriate dispersion model methodology for the tideflats area.

1.3 AMBIENT AIR QUALITY STANDARDS AND CLASS II PSD INCREMENTS APPLICABLE TO THE TIDEFLATS SOURCES

The combined emissions from the existing and proposed SO_2 sources located in and adjacent to the Tacoma tideflats area must comply with the National Ambient Air Quality Standards (NAAQS), the Washington State ambient air quality standards and the Puget Sound ambient air quality standards. Additionally, the combined emissions from sources subject to the Prevention of Significant Deterioration (PSD) Regulations (for example, the Tacoma City Light cogeneration plant) must comply with the Class II PSD Increments. Table 1-1 gives the National, Washington State and Puget Sound SO_2 ambient air quality standards as well as the SO_2 Class II PSD Increments. All of the ambient air quality standards and PSD Increments in Table 1-1 are given in units of parts per million (ppm) because these are the units used to define the Washington State and Puget Sound air quality standards. The NAAQS for SO_2 are defined in units of either ppm or micrograms per cubic meter, while the PSD Increments for SO_2 are defined in units of micrograms per cubic meter. One ppm of SO_2 is equal to 2,620 micrograms per cubic meter. For example, the 3-hour, 24-hour and annual Class II PSD Increments of 0.195, 0.035 and 0.008 ppm are respectively equal to 512, 91 and 20 micrograms per cubic meter.

TABLE 1-1

AMBIENT AIR QUALITY STANDARDS AND CLASS II PSD INCREMENTS FOR SO_2 APPLICABLE TO THE TIDEFLATS SOURCES

Time Period	National Standards (ppm)		Washington State Standards (ppm)	Puget Sound Standards (ppm)	Class II PSD Increment (ppm)
	Primary	Secondary			
5 minutes	--	--	--	1.00[d]	--
1 hour	--	--	0.40[a]	0.40[b]	--
1 hour	--	--	0.25[c]	0.25[c]	--
3 hours	--	0.50[a]	--	--	0.195[a]
24 hours	0.14[a]	--	0.10[a]	0.10[b]	0.035[a]
30 days	--	--	--	0.04[b]	--
Annual	0.03[b]	--	0.02[b]	0.02[b]	0.008[b]

[a] Not to be exceeded at any given point more than once per year.

[b] Never to be exeeded.

[c] Not to be exceeded at any given point more than two times in any 7 consecutive days.

[d] Not to be exceeded at any given point more than once in any 8 consecutive hours.

Inspection of the footnotes at the bottom of Table 1-1 shows that the National, Washington State and Puget Sound annual ambient air quality standards may never be exceeded. Also, the Puget Sound 30-day and 24-hour ambient air quality standards and one of the two Puget Sound 1-hour standards may never be exceeded. The remaining ambient air quality standards may be exceeded at any given point (receptor) one or more times per year, depending on the standard. For example, a short-term NAAQS or PSD Increment is violated at a given point during the second short-term period in a year with a short-term concentration above the corresponding NAAQS or PSD Increment. In general, the same definition of a violation of a short-term NAAQS or PSD Increment is applied to the results of dispersion model calculations. That is, the second-highest short-term concentration calculated for a receptor during a year normally is used to assess the compliance of the receptor with the corresponding NAAQS or PSD Increment. However, as noted in the current Guideline on Air Quality Models (EPA, 1978), air pollution control agencies may specify that the highest rather than the highest of the second-highest short-term concentrations calculated for all receptors be used to evaluate compliance with the short-term NAAQS and PSD Increments if there are uncertainties about the representativeness of the data available for input to the dispersion model. We recommend that the dispersion model methodology for the Tacoma tideflats area use the highest rather than the highest of the second-highest calculated short-term concentrations to assess compliance with all of the short-term ambient air quality standards and PSD Increments listed in Table 1-1 for two reasons. First, the most restrictive short-term air quality standards are the Puget Sound standards which may never be exceeded. Second, there are uncertainties about the applicability of the available meteorological data under all meteorological conditions because of the complexity of the terrain in the tideflats area. Our recommendation does not apply to the Puget Sound 5-minute standard of 1 ppm (not to be exceeded at any given point more than once in any 8 consecutive hours) nor to the Puget Sound and Washington State 1-hour standards of 0.25 ppm (not to be exceeded at any given point more than two times in any 7 consecutive days). These two standards are virtually impossible to address with any of the currently available dispersion modeling techniques. For consistency with the Puget Sound ambient air quality standards, we recommend that maximum running mean 3-hour and 24-hour average concentrations be used to assess compliance with the 3-hour and 24-hour ambient air quality standards and PSD Increments.

1.4 REPORT ORGANIZATION

In addition to the Introduction, this report contains five major sections and three appendices. Section 2 gives the SHORTZ/LONGZ SO_2 emissions inventory for the existing and proposed sources in the Tacoma tideflats area. Section 3 summarizes our analysis of the available meteorological and air quality data and also includes a discussion of several model calculations which were made to evaluate possible modeling approaches. In Section 4, statistical procedures suggested in the August 1981 draft EPA report "Interim Procedures for Evaluation of Air Quality Models" are applied to the results of the SHORTZ/LONGZ concentration calculations for the Tacoma area that are given in Appendix E of the report by Cramer, et al. (1976). Section 5 outlines a preliminary SHORTZ/LONGZ dispersion model methodology for the tideflats area and Section 6 contains suggestions for future work to refine this methodology. The mathematical equations implemented by the SHORTZ/LONGZ computer codes are discussed in Appendix A. More detailed documentation and user's instructions for the SHORTZ/LONGZ models are contained in the report by Bjorklund and Bowers (1982). Appendix B lists the receptor inputs suggested for the tideflats and adjacent areas. Hourly SHORTZ inputs for selected "worst-case" short-term periods and an annual wind summary for input to LONGZ are listed in Appendix C.

SECTION 2

SHORTZ/LONGZ EMISSIONS INVENTORY FOR THE EXISTING AND PROPOSED SO_2 SOURCES

The SO_2 emissions inventory for the major existing and proposed sources in and adjacent to the Tacoma, Washington tideflats area was developed from information provided by:

- The Puget Sound Air Pollution Control Agency (PSAPCA, 1982)
- The U. S. Environmental Protection Agency, Region 10 (Wilson, 1982a and 1982c)
- Kaiser Aluminum & Chemical Corporation (Schmeil, 1982)

Additionally, a layout of the ASARCO smelter, acquired by the H. E. Cramer Company during a previous study of the smelter (Cramer, et al., 1976), was used to develop source inputs for fugitive emissions from the ASARCO smelter.

Table 2-1 identifies by source number the existing and proposed SO_2 sources located in and adjacent to the tideflats. The source parameters in the format required for input to the SHORTZ/LONGZ dispersion models are listed in Table 2-2. Source Type 0 is a stack source and Source Type 1 is a building source. The SHORTZ/LONGZ building source option is applied to the fugitive emissions from the ASARCO smelter and to the roof monitor emissions from the Kaiser aluminum plant. It is important to note that the stack radius should be entered as zero in the SHORTZ/LONGZ calculations for each stack with a radius enclosed by parentheses in Table 2-2. A zero stack radius deletes the Cramer, et al. (1975) stack-tip downwash correction in SHORTZ/LONGZ calculations. Based on the stack's Froude number and our previous experience (See Appendix G of Bjorklund and Bowers, 1982), we do not believe that the Cramer, et al. stack-tip downwash correction is appli-

TABLE 2-1

IDENTIFICATION BY SOURCE NUMBER OF EXISTING AND PROPOSED SO_2 SOURCES IN AND ADJACENT TO THE TACOMA TIDEFLATS AREA

Source No.	Source Name	Existing	Proposed
101	ASARCO Main Stack	x	
102	ASARCO Fugitive Emissions	x	
201	St. Regis Boiler No. 1	x	
202	St. Regis Boilers No. 3 - No. 5	x	
203	St. Regis Boiler No. 6	x	
204	St. Regis Lime Kiln No. 1	x	
205	St. Regis Recovery Boiler No. 3	x	
206	St. Regis Recovery Boiler No. 4	x	
301 & 302	Kaiser Potlines 1 and 2	x	
303 - 308	Kaiser Potline 4	x	
309 - 316	Kaiser Potline 5		x
317 - 320	Kaiser Lines 1 and 2 Dry Scrubber Stacks	x	
321 - 324	Kaiser Line 4 Dry Scrubber Stacks	x	
325	Kaiser Bake Oven Stack		x
326	Kaiser Line 5 Dry Scrubber Stack		x
401	Pennwalt Boiler/Pots	x	
402	Pennwalt B & W Boiler	x	
403	Pennwalt G & S Boiler	x	
501	U. S. Oil & Refining Flare Stacks	x	
502	U. S. Oil & Refining Power Boilers 1-3	x	
503	U. S. Oil & Refining Heater H-3	x	
504	U. S. Oil & Refining Heater H-8	x	
505	U. S. Oil & Refining H-11, 801 & 901	x	
601	Occidental Chemical Corp. Hooker Division Boilers	x	
701	Tacoma City Light Cogneration Plant		x

TABLE 2-2

SHORTZ/LONGZ SOURCE INPUT PARAMETERS FOR THE EXISTING AND PROPOSED SO_2 SOURCES IN THE TACOMA TIDEFLATS AREA

Source No.	Source Type	SO_2 Emission Rate (g/sec)	UTM X (m)	UTM Y (m)	Stack Height (m) for Type 0 or Effective Emission Height (m) for Type 1	Stack or Building Base Elevation (m MSL)	Exit Temperature (°K) for Type 0 or Length of Short Side (m) for Type 1	Exit Volume (m^3/sec) for Type 0 or Length of Long Side (m) for Type 1	Stack Radius (m) for Type 0* or Angle (deg) to Long Side for Type 1
101	0	2540.00	537,350	5,238,080	172	43	366	376.7	(3.65)
102	1	62.00	537,400	5,238,400	30	9	38	30.0	135
201	0	6.00	543,450	5,234,700	25	3	419	16.3	0.70
202	0	1.00	543,450	5,234,700	41	3	333	64.8	1.15
203	0	27.00	543,450	5,234,700	30	3	447	39.6	1.00
204	0	1.00	543,500	5,234,650	30	3	348	17.5	0.70
205	0	5.00	543,400	5,234,750	81	3	341	48.2	1.45
206	0	10.00	543,400	5,234,750	77	3	460	161.2	2.15
301	1	2.10	547,875	5,234,054	15.2	3	91	107	0
302	1	2.10	547,875	5,233,947	15.2	3	91	107	0
303	1	0.48	547,715	5,234,210	15.2	3	60	60	0
304	1	0.48	547,715	5,234,150	15.2	3	60	60	0
305	1	0.48	547,715	5,234,090	15.2	3	60	60	0
306	1	0.48	547,715	5,234,030	15.2	3	60	60	0
307	1	0.48	547,715	5,233,970	15.2	3	60	60	0
308	1	0.48	547,715	5,233,910	15.2	3	60	60	0
309	1	0.26	547,525	5,234,330	16.8	3	60	60	0
310	1	0.26	547,525	5,234,270	16.8	3	60	60	0
311	1	0.26	547,525	5,234,210	16.8	3	60	60	0
312	1	0.26	547,525	5,234,150	16.8	3	60	60	0
313	1	0.26	547,525	5,234,090	16.8	3	60	60	0
314	1	0.26	547,525	5,234,030	16.8	3	60	60	0

TABLE 2-2 (Continued)

Source No.	Source Type	SO_2 Emission Rate (g/sec)	UTM X (m)	UTM Y (m)	Stack Height (m) for Type 0 or Effective Emission Height (m) for Type 1	Stack or Building Base Elevation (m MSL)	Exit Temperature (°K) for Type 0 or Length of Short Side (m) for Type 1	Exit Volume (m^3/sec) for Type 0 or Length of Long Side (m) for Type 1	Stack Radius (m) for Type 0* or Angle (deg) to Long Side for Type 1
315	1	0.26	547,525	5,233,970	16.8	3	60	60	0
316	1	0.26	547,525	5,233,910	16.8	3	60	60	0
317	0	6.60	548,325	5,234,175	15.8	3	344	69.7	1.74
318	0	5.28	548,615	5,234,175	15.8	3	344	69.7	1.74
319	0	6.60	548,325	5,234,152	15.8	3	344	69.7	1.74
320	0	5.28	548,615	5,234,152	15.8	3	344	69.7	1.74
321	0	7.20	547,574	5,233,958	15.8	3	344	68.2	1.74
322	0	7.20	547,595	5,233,958	15.8	3	344	68.2	1.74
323	0	5.76	547,574	5,233,931	15.8	3	344	68.2	1.74
324	0	5.76	547,595	5,233,931	15.8	3	344	68.2	1.74
325	0	1.56	547,458	5,234,116	15.2	3	388	34.0	0.71
326	0	51.54	547,608	5,233,990	152.4	3	344	234.0	(3.96)
401	0	9.00	547,350	5,234,950	46	3	450	3.5	(1.05)
402	0	9.00	547,350	5,234,950	18	3	533	12.3	0.60
403	0	9.00	547,350	5,234,950	18	3	533	11.3	(0.75)
501	0	2.00	545,700	5,233,500	12	3	811	0.14	(0.10)
502	0	3.00	545,900	5,233,500	49	3	627	16.40	0.75
503	0	1.00	545,700	5,233,500	43	3	711	23.10	0.70
504	0	1.00	545,700	5,233,500	24	3	783	3.50	(0.45)
505	0	5.00	545,700	5,233,500	29	3	672	6.40	0.45

the proposed new Kaiser sources were not known during the course of our study, we have used the information available for these sources to develop source inputs to serve as a guide in the development of future SHORTZ/LONGZ source inputs.

The Kaiser potline emissions are horizontally discharged from building roof monitors at a temperature approximately 14 degrees Celsius above the ambient air temperature. These low-level emissions are rapidly distributed by the cavity circulation of the aerodynamic wake of the potroom complex and quickly assume the dimensions of the complex. The SHORTZ/LONGZ building source option currently cannot address the buoyant rise of the roof monitor emissions. Because the roof monitor emissions account for only 12 percent of the total SO_2 emissions from the existing Kaiser plant, our current emissions inventory uses the SHORTZ/LONGZ building source option to model the potline emissions with the effective emission height defined as the actual emission height. The Potroom 1 and 2 complex is represented in Table 2-2 by two building sources, the Potroom 4 complex is represented by six building sources and the Potroom 5 complex is represented by eight building sources. As explained in Section 2.3.2 in the report by Bjorklund and Bowers (1982), multiple subsources with approximately equivalent lengths and widths are used to maintain computational accuracy.

It is important to recognize that the neglect of the buoyant rise of the emissions from roof monitors at the Kaiser plant will tend to overestimate the impact of these emissions within about the first kilometer downwind, especially under light wind conditions. If the impact of these emissions becomes of critical concern, the building source option of the SHORTZ/LONGZ models could be modified to use simplified forms of the line source plume rise equations utilized by the Aluminum Association's Buoyant Line and Point Source (BLP) Dispersion Model (Schulman and Scire, 1980). For winds normal to the potlines, the final rise of the roof monitor emissions under adiabatic or unstable conditions is given by the solution to the following equation:

$$\Delta h_{NL}^{3} + \frac{3L}{\pi \gamma_1} \Delta h_{NL}^{2} + \left(\frac{3h_b}{\gamma_1} \Delta h_{NL} + \frac{6h_b L}{\pi \gamma_1^2} + \frac{3h_b^2}{\gamma_1^2} \right) \Delta h_{NL} = \frac{3 F' x_f^2}{2\pi \bar{u}\{h\}^3 \gamma_1^2} \qquad (2\text{-}1)$$

$$F' = g L W w_e \left(1 - \frac{T_a}{T_s} \right) \qquad (2\text{-}2)$$

$$x_f = \begin{cases} 49\left(\frac{F'}{\pi}\right)^{5/8} & ; \frac{F'}{\pi} \le 55 \text{ m}^4/\text{sec}^3 \\ 119\left(\frac{F'}{\pi}\right)^{2/5} & ; \frac{F'}{\pi} > 55 \text{ m}^4/\text{sec}^3 \end{cases} \qquad (2\text{-}3)$$

where

Δh_{NL} = the line source plume rise under adiabatic or unstable conditions (m)

L = the length of the roof monitor (m)

h_b = the height of the potline buildings (m)

γ_1 = the adiabatic entrainment coefficient ~ 0.6 (Briggs, 1972)

$\bar{u}\{h\}$ = the mean wind speed at the roof monitor emission height (m/sec)

g = the acceleration due to gravity (m/sec^2)

W = the width of the roof monitor (m)

w_e = the effective exit velocity of the roof monitor emissions (m/sec)

T_s = the exit temperature of the roof monitor emissions (°K)

T_a = the ambient air temperature (°K)

For winds normal to the potlines, the final rise of the roof monitor emissions under stable conditions Δh_{SL} is given by the solution to an equation which is identical to Equation (2-1) except that the stable entrainment coefficient $\gamma_2 \sim 0.66$ (Briggs, 1972) is substituted for γ_1 and the term at the far right of Equation (2-1) is replaced by

$$\frac{6F'}{\pi \gamma_2^2 \bar{u}\{h\} S} \qquad (2\text{-}4)$$

$$S = \frac{g}{T_a} \frac{\partial \theta}{\partial z} \qquad (2\text{-}5)$$

where $\partial\theta/\partial z$ is the vertical potential temperature gradient in degrees Kelvin per meter. If a stable potential temperature gradient is entered, the plume rise used in the model calculations should be the minimum of the rises given by the adiabatic and stable rise equations. We suggest that the buoyancy flux F' for each potroom complex be set equal to the sum of the fluxes for the two roof monitors. The plume rise calculated for each potroom complex should be assigned to each subsource used to represent the complex.

The dry scrubber stacks for Kaiser Potlines 1 and 2 are grouped in two parallel rows of stack clusters with an east-to-west row orientation. Each individual stack cluster contains four stacks in a north-to-south line. The dry scrubber stacks for Potline 4 have the same configuration except that the parallel rows of stack clusters are rotated 90 degrees and thus have a north-to-south orientation. Four stacks per cluster, nine clusters per row and two rows per dry scrubber system yield 72 individual stacks per dry scrubber system. To preserve the horizontal geometry of these dry scrubber stacks, we assigned two model stacks per row of stack clusters. The location of each model stack is at the centroid of the four or five stack clusters which it represents, while the SO_2 emission rate is equal to the combined emission rate for the four or five stack clusters. Because of the close proximity of the stacks, some enhancement in buoyant plume rise can be expected as the result of the merging of individual stack plumes. To account for this enhancement in plume rise, we assigned to the model stacks effective volumetric emission rates which are based on a semi-empirical approach developed by Briggs (1974).

Briggs (1974) gives the enhancement in buoyant plume rise for a row of n stacks as

$$E = \frac{\Delta h_n}{\Delta h_1} = \left[\frac{n+S}{1+S}\right]^{1/3} \tag{2-6}$$

$$S = 6\left[\frac{(n-1)s}{n^{1/3}\ \Delta h_1}\right]^{3/2} \tag{2-7}$$

where Δh_n is the plume rise for the merged plume, Δh_1 is the plume rise for an individual (isolated) plume and s is the center-to-center stack spacing. Briggs (1974, p. 27) notes that, "While the empirical enhancement was developed using line source data, it is suggested that it could be conservatively applied to clusters of sources by replacing (n-1)s with the maximum diameter of the cluster." We assumed that the "maximum diameter" for each dry scrubber system is the length of a row of parallel stack clusters. Also, we assumed that Δh_1 typically is on the order of the stack height h. The Briggs (1971, 1972) plume rise equations used by SHORTZ/LONGZ assume that the buoyant plume rise is proportional to the cube root of the volumetric emission rate. It follows that the effective volumetric emission rate V_{eff} for use in the model plume rise calculations may be obtained by solving the expression

$$E = \frac{\Delta h_{72}}{\Delta h_1} = \left(\frac{V_{eff}}{V_1}\right)^{1/3} \qquad (2\text{-}8)$$

where V_1 is the volumetric emission rate for a single stack. Under the above assumptions, the enhancement factor E is 2.60.

In addition to the use of an effective volumetric emission rate for each of the model dry scrubber stacks, an effective stack radius is assigned to each dry scrubber stack in Table 2-2 in order to maintain the actual stack exit velocity for use in the stack-tip downwash calculations. We believe that the Cramer, et al. (1975) stack-tip downwash correction probably is adequate to account for the effects on buoyant plume rise of the aerodynamic wakes of the plant buildings (see Section 3.4 of Bowers and Anderson, 1981). However, with moderate or strong winds there is likely to be an enhancement in the initial rate of dispersion of the emissions from the dry scrubber stacks that is not accounted for in the model calculations. The effects of this enhancement on the accuracy of the ground-level concentrations calculated by SHORTZ or LONGZ at distances more than about 200 meters from the dry scrubber stacks probably are minimal.

SECTION 3

REVIEW OF THE AVAILABLE METEOROLOGICAL AND SO_2 AIR QUALITY DATA

3.1 REVIEW OF THE AVAILABLE METEOROLOGICAL DATA

Figure 3-1 shows the locations of the PSAPCA and ASARCO wind measurement sites in and adjacent to the Tacoma tideflats area. These locations may be summarized as follows:

- The ASARCO Meeker Junior High School site is on the high terrain north of the tideflats (Brown's Point area)
- The ASARCO Ruston and Reservoir sites are northwest of the tideflats on the elevated terrain of the Tacoma peninsula
- Although not shown in Figure 3-1, the ASARCO Benny's (N26th & Pearl) site and the PSAPCA N26th & Pearl site are about 660 meters south-southwest of the ASARCO Reservoir site
- The PSAPCA Federal Way site is on high terrain northeast of the tideflats (see the upper right-hand corner of Figure 3-1)
- The PSAPCA Fire Station No. 12 site is near the center of the tideflats
- The PSAPCA Willard School site is on the rising terrain at the southwestern edge of the tideflats

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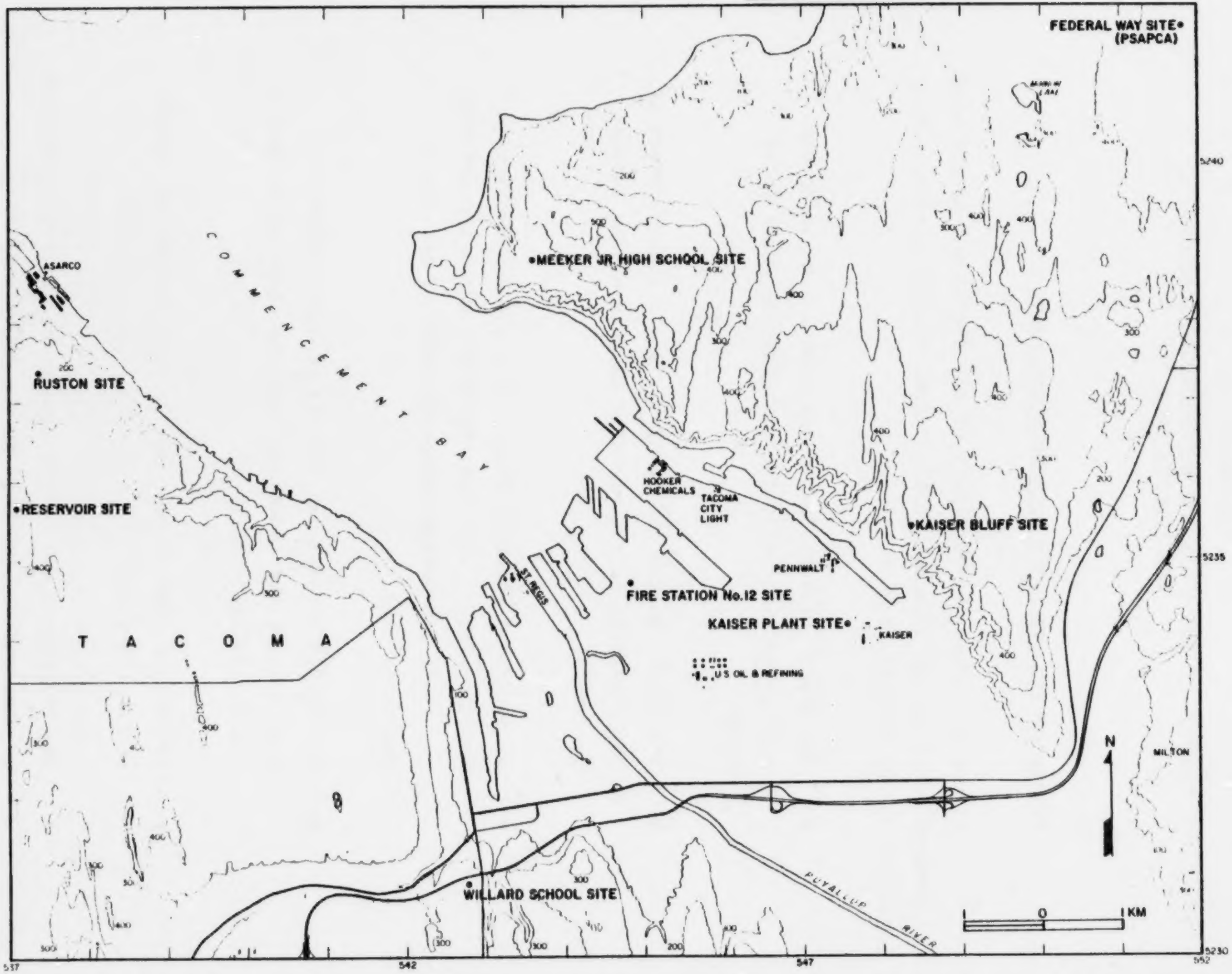

Figure 3-1. Topographic map of the Tacoma tideflats area showing the locations of the existing and proposed SO2 sources and the wind and/or SO2 air quality monitoring sites. Elevations are in feet above mean sea level, and the contour interval is 100 feet (30.5 meters).

PSAPCA (Knechtel, 1982) provided the H. E. Cramer Company with a computer tape containing the 1981 hourly wind data from all PSAPCA sites in and adjacent to the Tacoma tideflats area and ASARCO (Watson, 1982) provided EPA Region 10 with a computer tape containing the 1981 30-minute average wind data from the Benny's and Meeker sites. We used our Meteorological and Air Quality Statistical Analysis Program (MAQSAP) to analyze the wind data from the PSAPCA Fire Station No. 12, Willard School and N26th & Pearl sites and the ASARCO Benny's and Meeker sites. Table 3-1 give the locations and elevations of these sites. The following time-of-day categories were considered in the MAQSAP analyses:

- Morning - Sunrise plus 1 hour to sunrise plus 5 hours
- Afternoon - Sunrise plus 5 hours to sunset minus 1 hour
- Evening - Sunset minus 1 hour to sunset plus 2 hours
- Night - Sunset plus 2 hours to sunrise plus 1 hour

Highlights of the MAQSAP analyses of the wind data are discussed below.

Average Wind Directions and Speeds

Table 3-2 lists, by season and time-of-day category, the average wind directions and wind speeds at the PSAPCA Fire Station NO. 12, Willard School and N26th & Pearl sites and the ASARCO Benny's (N26th & Pearl) and Meeker sites. With the exception of the Meeker site, the annual average wind speeds at the various sites differ by 0.2 meters per second or less in spite of the fact that the elevations above mean sea level of the wind sensors vary by as much as 112 meters. The Meeker site, which is on elevated terrain near the tip of Brown's Point, is not as sheltered by overland fetch as are the two N26th & Pearl sites or by surrounding terrain as are the Fire Station No. 12 and Willard School sites. Thus, the average wind speeds at the Meeker site are consistently higher than at the other

TABLE 3-1

UNIVERSAL TRANSVERSE MERCATOR (UTM) COORDINATES AND ELEVATIONS ABOVE MEAN SEA LEVEL (MSL) OF THE WIND MEASUREMENT SITES

Site	Operator	UTM X (km)	UTM Y (km)	Ground Elevation (m MSL)	Wind Measurement Height (m AGL)
Fire Station No. 12	PSAPCA	544.83	5,234.75	3	16.8
Willard School	PSAPCA	524.81	5,230.87	87	11.3
N26th & Pearl	PSAPCA	536.68	5,235.15	123	9.1
Benny's (N26th & Pearl)	ASARCO	536.65	5,235.12	122	5.5
Meeker Jr. High School	ASARCO	543.60	5,238.75	104	4.6

TABLE 3-2

1981 AVERAGE WIND DIRECTIONS AND WIND SPEEDS BY SEASON AND TIME-OF-DAY CATEGORIES

Time of Day	Average Wind Direction (deg)/Average Wind Speed (m/sec)				
	Winter	Spring	Summer	Fall	Annual
(a) PSAPCA Fire Station No. 12					
Night	155/1.6	169/1.7	228/1.4	151/1.6	165/1.6
Morning	174/1.8	199/2.0	233/1.6	174/1.9	195/1.8
Afternoon	273/2.3	275/3.4	295/3.1	294/2.8	287/3.0
Evening	192/2.0	251/2.7	287/2.4	218/2.1	264/2.3
Average	166/1.8	222/2.5	276/2.3	170/2.0	218/2.1
(b) PSAPCA Willard School					
Night	200/1.6	202/1.9	219/1.4	194/1.6	204/1.6
Morning	203/1.6	208/2.0	220/1.4	204/1.8	210/1.7
Afternoon	281/2.2	258/3.0	294/2.6	280/2.6	278/2.6
Evening	221/2.1	232/2.5	267/2.0	219/2.1	244/2.2
Average	207/1.8	223/2.4	255/2.0	213/1.9	229/2.0
(c) PSAPCA N26th & Pearl					
Night	153/1.8	194/2.0	119/1.6	166/1.8	190/1.8
Morning	190/1.9	216/2.2	227/1.8	196/2.1	214/2.0
Afternoon	268/2.3	251/2.9	268/2.6	263/2.1	261/2.6
Evening	097/2.0	233/2.3	270/2.0	148/2.0	245/2.1
Average	168/1.9	224/2.4	252/2.1	187/2.1	226/2.1
(d) ASARCO Benny's (N26th & Pearl)					
Night	153/1.7	200/2.3	235/1.9	168/1.7	192/1.9
Morning	204/1.9	224/2.7	231/2.1	192/2.0	220/2.2
Afternoon	287/2.2	256/3.3	270/2.9	262/2.4	265/2.9
Evening	122/2.0	237/2.7	272/2.3	141/2.0	244/2.2
Average	168/1.9	229/2.8	255/2.4	190/2.0	229/2.3

TABLE 3-2 (Continued)

Time of Day	Average Wind Direction (deg)/Average Wind Speed (m/sec)				
	Winter	Spring	Summer	Fall	Annual
(d) ASARCO Meeker Junior High School					
Night	114/3.1	149/2.9	190/2.2	123/3.0	132/2.9
Morning	170/3.1	198/2.9	211/2.2	177/3.1	192/2.8
Afternoon	235/3.5	258/3.6	284/3.3	277/3.7	272/3.5
Evening	091/3.4	227/3.4	310/2.9	092/3.5	079/3.3
Average	121/3.2	201/3.2	259/2.7	133/3.3	174/3.1

sites. It is important to note that PSAPCA computes vector mean wind directions and speeds, whereas ASARCO computes scalar mean wind directions and speeds. If the same instantaneous wind observations are used to calculate vector and scalar mean wind speeds, the vector mean wind speeds should be less than or equal to the scalar mean wind speeds. We believe that the differences in the techniques used by PSAPCA and ASARCO to calculate mean wind directions and speeds probably account for the fact that the ASARCO Benny's average wind speeds at 5.5 meters above ground level generally are slightly higher than the PSAPCA N26th & Pearl average wind speeds at a height of 9.1 meters above ground level. In our previous dispersion model study of the Tacoma area (Cramer, et al., 1976), we assumed that the wind speed at the PSAPCA N26th & Pearl site was representative of the wind speed at all elevations below the height above mean sea level of the wind sensor. Table 3-2 indicates that, at least on the average, this is a reasonable assumption for the tideflats sources.

The differences in the average wind directions listed in Table 3-2 in part reflect localized effects and are more significant for dispersion modeling purposes than are the differences in average wind speeds. For example, the south-southeast winds found on winter nights at Fire Station No. 12 and the two N26th & Pearl sites appear to be channeled by adjacent terrain into south-southwest winds at Willard School and east-southeast winds at the Meeker site. On the average, there is a close correspondence between the average wind directions at the two N26th & Pearl sites. The differences in average wind directions given in Table 3-2 for the two N26th & Pearl sites probably are primarily attributable to the different techniques used by PSAPCA and ASARCO to compute mean wind directions and speeds.

Wind-Direction Distributions

Figure 3-2 shows the Fire Station No. 12 annual wind-direction distributions for the night, morning, afternoon and evening time-of-day categories. The directions in Figure 3-2 are directions from which the wind is blowing. Comparison of Figures 3-1 and 3-2 shows that the elevated

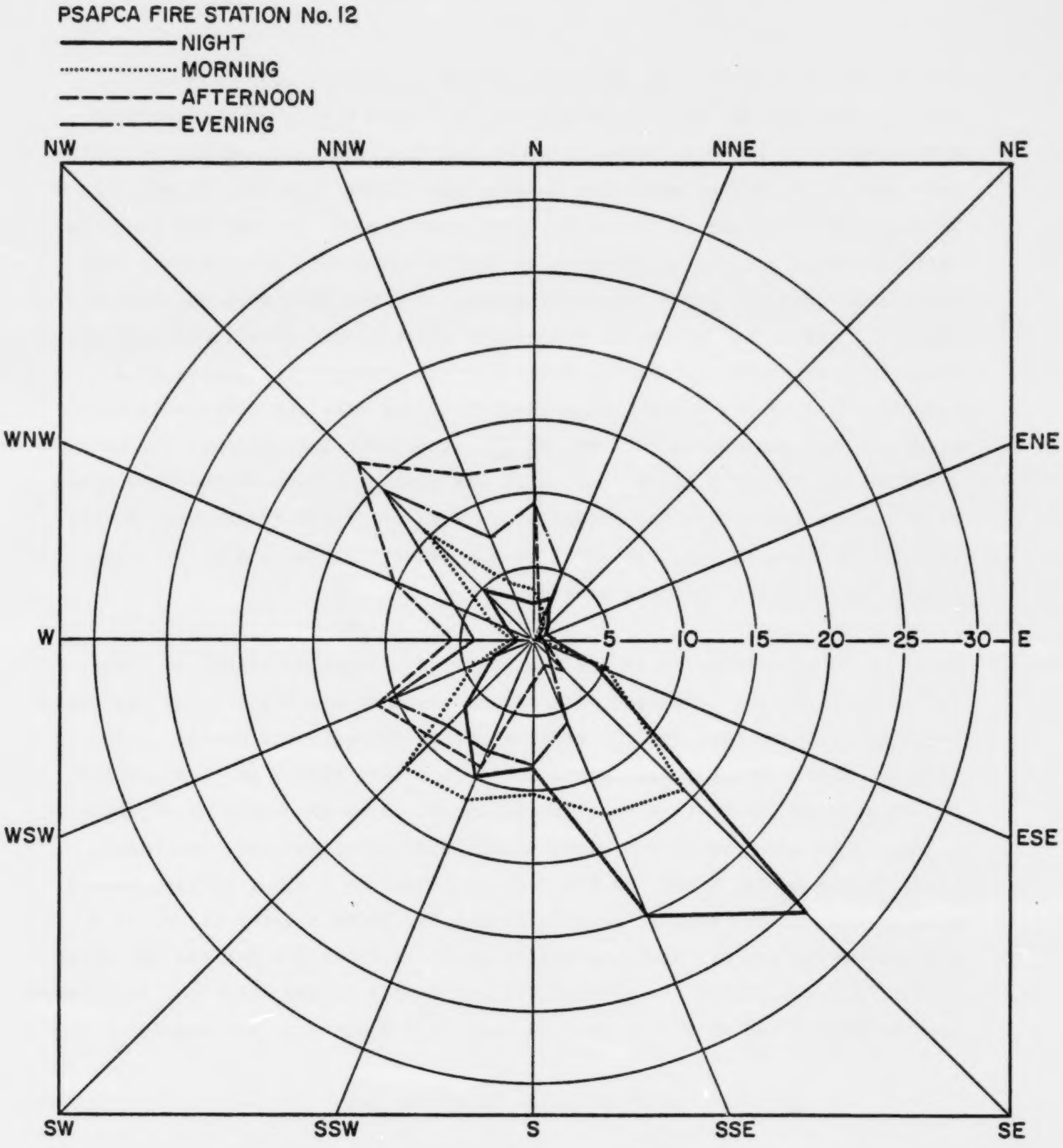

Figure 3-2. PSAPCA Fire Station No. 12 1981 annual wind-direction distributions for the night, morning, afternoon and evening time-of-day categories. Directions are directions from which the wind is blowing, and the percentage frequency scale is shown at the right center of the figure.

terrain on either side of the tideflats results in a highly channeled northwest-to-southeast flow. The predominance of offshore (southeast) winds during the night and, to a lesser extent, during the morning strongly suggests that these are low-level drainage winds. Because onshore (northwest) winds are most frequent during the afternoon and, to a lesser extent, during the evening, there is some evidence for a low-level sea-breeze type of circulation. Thus, the Fire Station No. 12 wind directions may not be representative of transport wind directions for emissions from many of the tideflats sources.

Figure 3-3 shows the Willard School annual wind-direction distributions for the four time-of-day categories. At first glance, there is very little correspondence between the wind-direction distributions at Willard School and Fire Station No. 12. As shown by a comparison of Figures 3-1 and 3-3, the winds at Willard School closely parallel the elevated terrain west of the site. In general, the winds at Willard School are either from the north or the south-southwest. Although the elevation above mean sea level of the Willard School wind sensor is near the typical plume stabilization height for the plumes from many of the sources in the tideflats area, the Willard School wind directions are unlikely to be representative of transport wind directions because of the localized terrain channeling of the winds.

Figure 3-4 shows the PSAPCA N26th & Pearl annual wind-direction distributions for the four time-of-day categories. The diurnal variations in the wind-direction distribution at N26th & Pearl are much less pronounced than at Willard School and Fire Station No. 12. For each time-of-day category, the N26th & Pearl wind-direction distribution has an approximate north-northeast to south-southwest or southwest orientation. If allowance is made for the localized terrain channeling at Willard School, the annual wind-direction distributions at N26th & Pearl and Willard School are consistent.

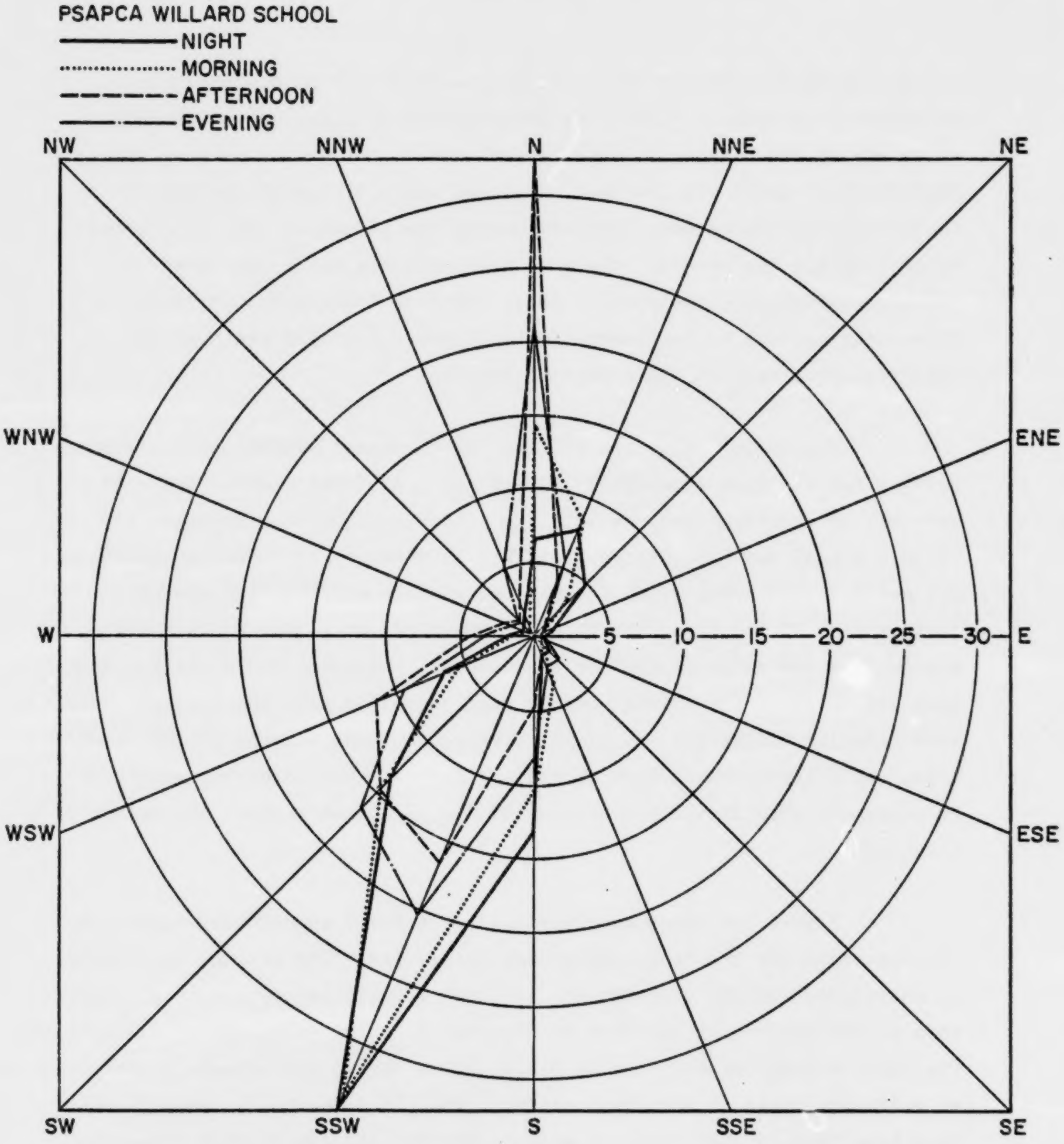

Figure 3-3. PSAPCA Willard School 1981 annual wind-direction distributions for the night, morning, afternoon and evening time-of-day categories. Directions are directions from which the wind is blowing, and the percentage frequency scale is shown at the right center of the figure.

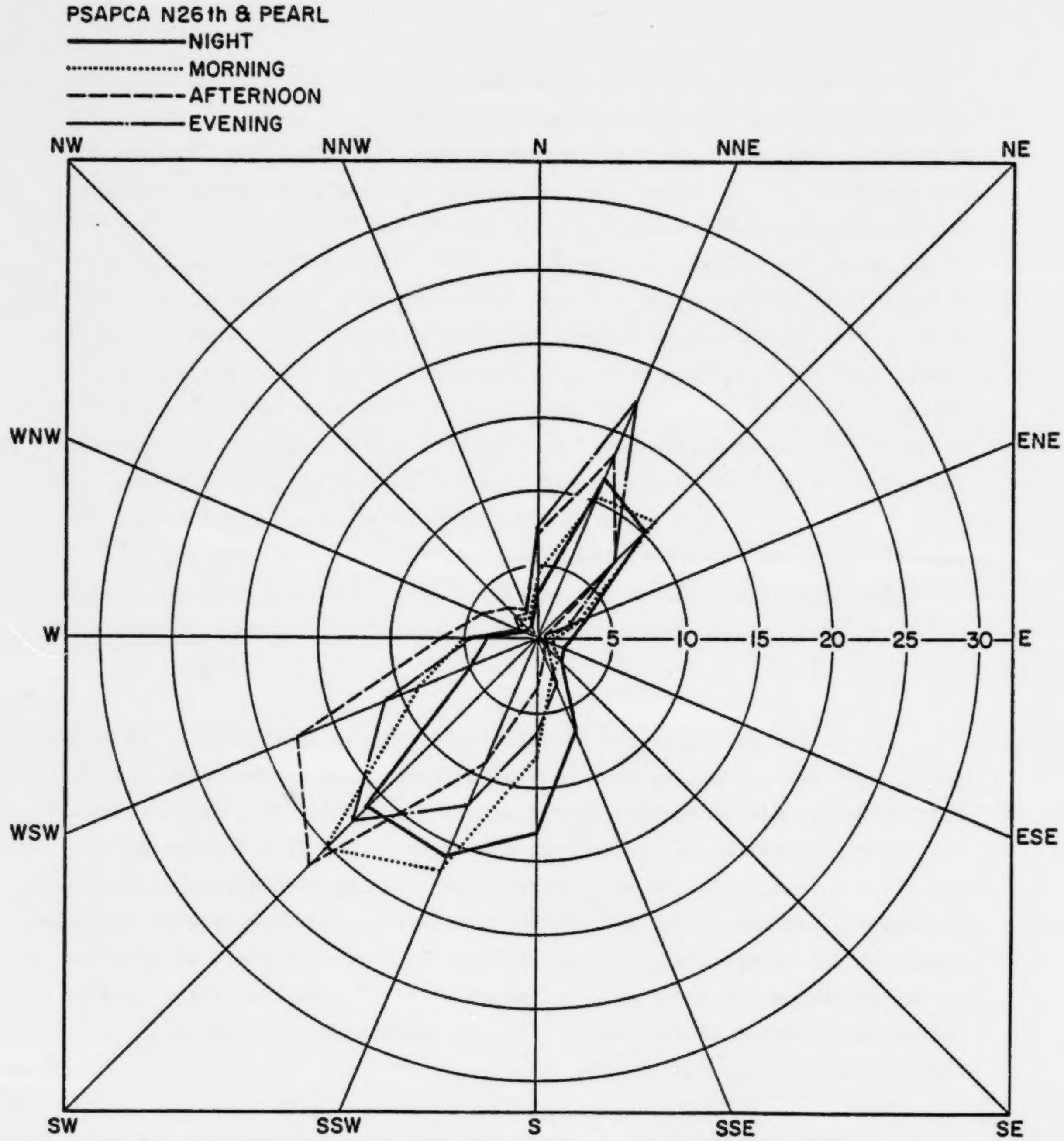

Figure 3-4. PSAPCA N26th & Pearl 1981 annual wind-direction distributions for the night, morning, afternoon and evening time-of-day categories. Directions are directions from which the wind is blowing, and the percentage frequency scale is shown at the right center of the figure.

Figure 3-5 shows the ASARCO Benny's (N26th & Pearl) annual wind-direction distributions for the four time-of-day categories. Inspection of Figures 3-4 and 3-5 shows that the annual wind-direction distributions for the two N26th & Pearl sites are very similar for each time-of-day category. To facilitate comparisons of the wind-direction distributions at the two sites, Figure 3-6 shows the PSAPCA and ASARCO N26th & Pearl annual wind-direction distributions for all time-of-day categories combined. The PSAPCA winds differ from the ASARCO winds in that the PSAPCA winds show a slightly higher frequency of winds from the north-northeast and a slightly lower frequency of winds from the northeast. With these exceptions, the differences in the two wind-direction distributions are negligible. An important feature of Figure 3-6 is the almost complete absence of winds from the east through east-southeast. Assuming the N26th & Pearl wind directions to be representative of transport wind directions for emissions from the tideflats sources as well as for emissions from the ASARCO smelter, Figure 3-6 shows that emissions from the tideflats sources are likely to have a

Figure 3-7 shows the annual wind-direction distributions at Meeker Junior High School for the four time-of-day categories. The night and morning Meeker wind-direction distributions are similar to a combination of the night and morning wind-direction distributions at Fire Station No. 12 and N26th & Pearl. The Meeker afternoon and evening wind-direction distributions are similar to the N26th & Pearl afternoon and evening wind-direction distributions except that the winds toward the north-northwest which occur at Meeker during the evening do not occur at N26th & Pearl. Winds toward the north-northwest at the Meeker site are consistent with channeling by the elevated terrain east of the site.

Some localized effects on winds such as nighttime draining winds are associated with light wind speeds. It is therefore of interest to examine the annual wind-direction distributions for all wind speeds and for moderate or strong wind speeds. The annual wind-direction distributions at

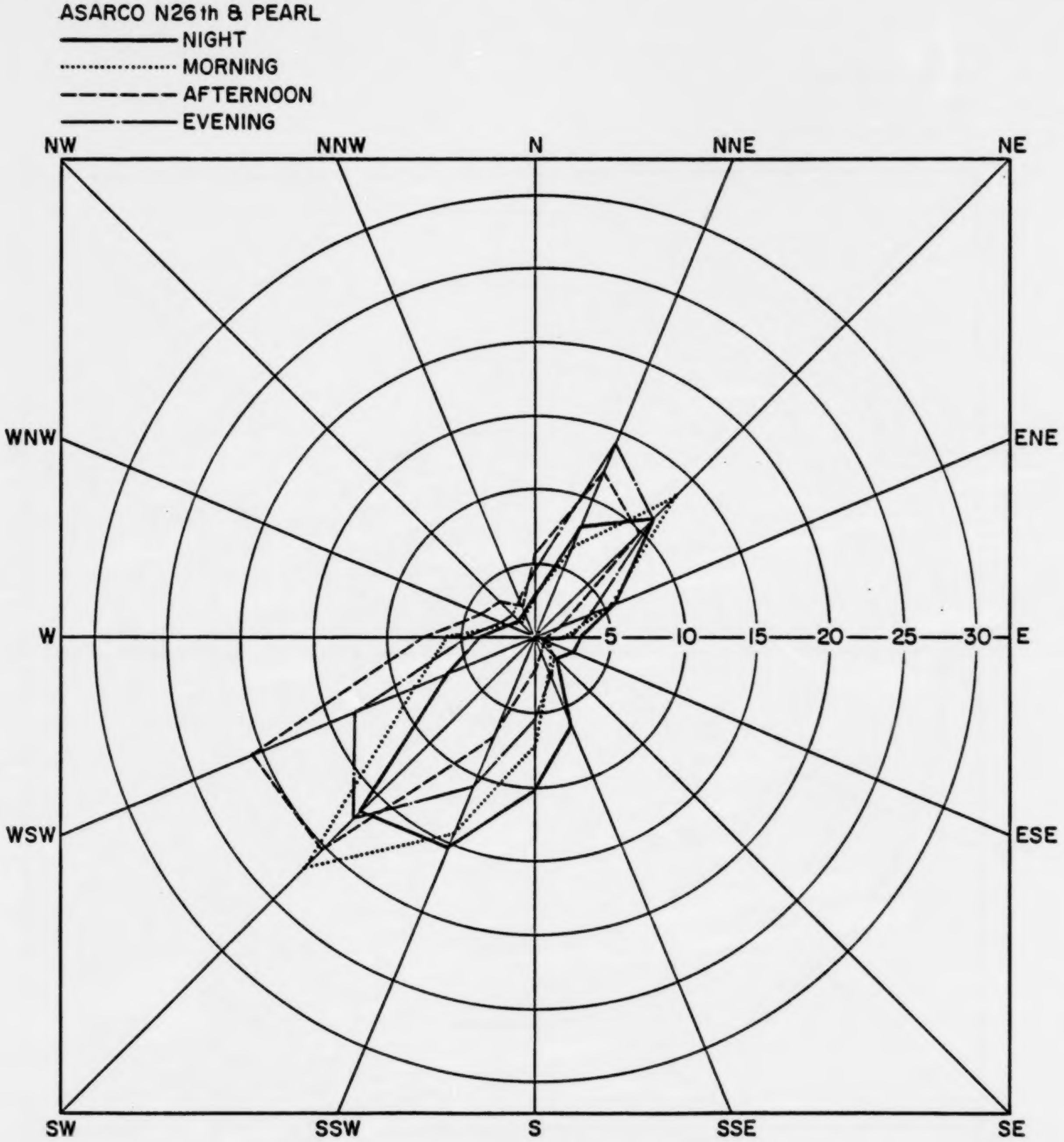

Figure 3-5. ASARCO Benny's (N26th & Pearl) 1981 annual wind-direction distributions for the night, morning, afternoon and evening time-of-day categories. Directions are directions from which the wind is blowing, and the percentage frequency scale is shown at the right center of the figure.

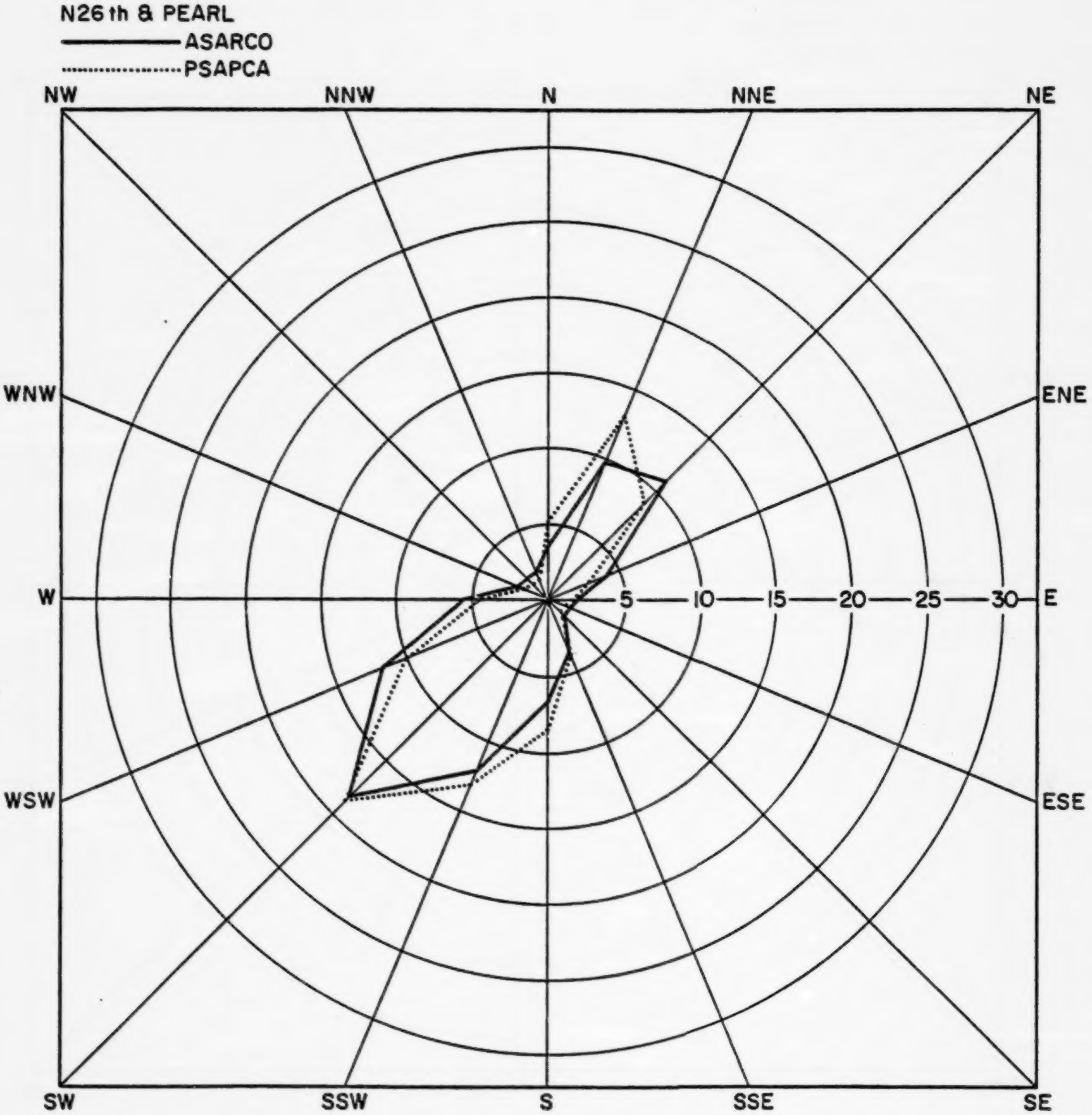

Figure 3-6. ASARCO and PSAPCA N26th & Pearl sites 1981 annual wind-direction distributions. Directions are directions from which the wind is blowing, and the percentage frequency scale is shown at the right center of the figure.

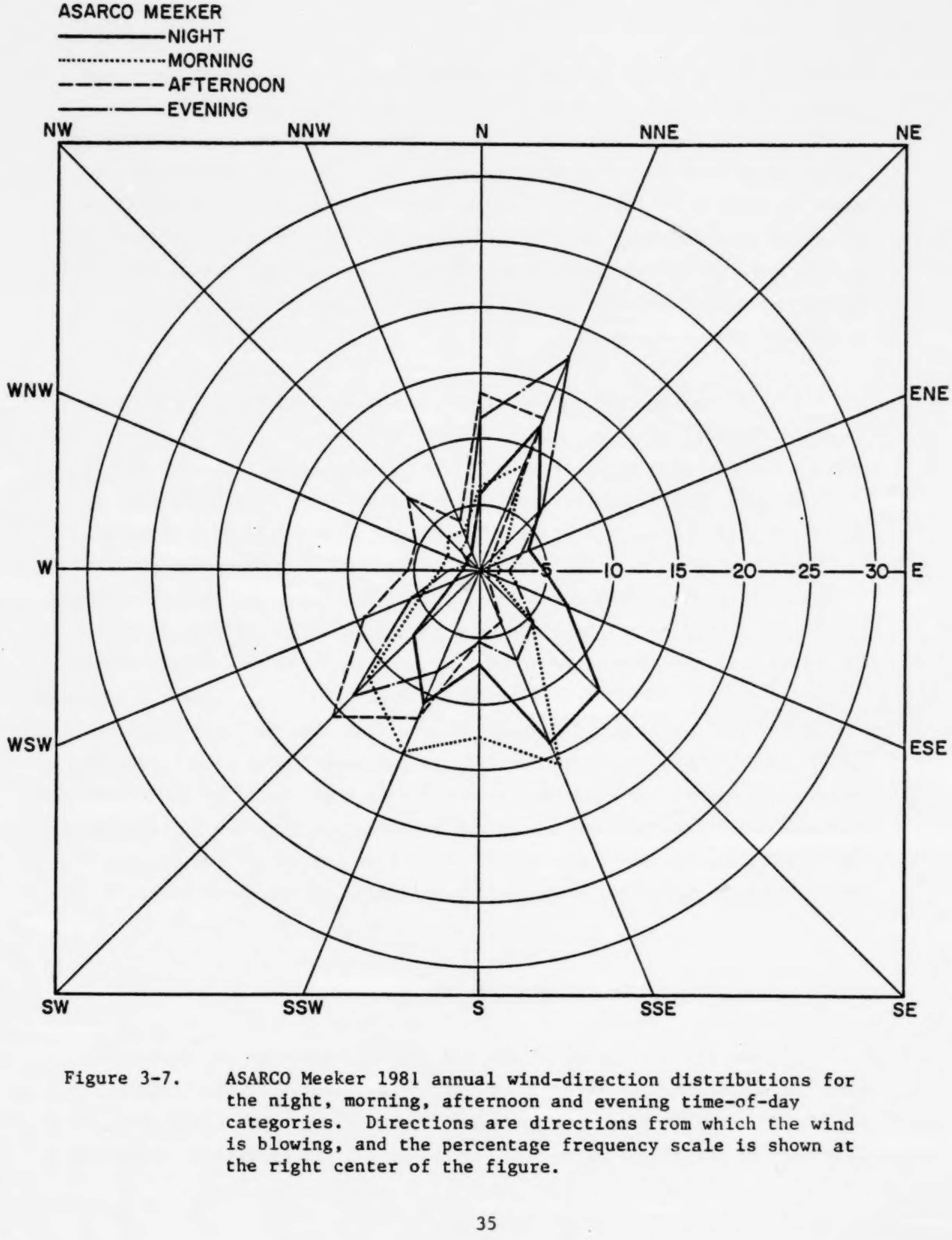

Figure 3-7. ASARCO Meeker 1981 annual wind-direction distributions for the night, morning, afternoon and evening time-of-day categories. Directions are directions from which the wind is blowing, and the percentage frequency scale is shown at the right center of the figure.

the three PSAPCA sites for all wind speeds and for wind speeds above 3.1 meters per second are shown in Figures 3-8 and 3-9, respectively. Similarly, the annual wind-direction distributions at the two ASARCO sites for all wind speeds and for wind speeds above 3.1 meters per second are shown in Figures 3-10 and 3-11, respectively. Although the annual wind-direction distributions for all wind speeds differ significantly from site to site, the annual wind-direction distributions for wind speeds above 3.1 meters per second are similar if allowance is made for terrain channeling at Willard School and Meeker.

In summary, our review of the annual wind-direction distributions from the PSAPCA Fire Station No. 12, Willard School and N26th & Pearl sites and the ASARCO Benny's (N26th & Pearl) and Meeker sites indicates that the N26th & Pearl wind directions are the only wind directions unaffected by localized influences. The Willard School and Meeker wind directions are influenced by terrain channeling and thus may not be representative of transport wind directions for emissions from the tideflats sources. During hours of moderate or strong winds, the Fire Station No. 12 wind directions are similar to the N26th & Pearl wind directions. However, during hours with light winds, the Fire Station No. 12 wind directions reflect a channeled nighttime offshore flow and daytime onshore flow that probably does not extend to the plume stabilization heights for many of the plumes from the tideflats sources. If wind data from a single site are to be used in dispersion model calculations for all of the existing and proposed SO_2 sources in the tideflats area, we conclude that winds from one of the two N26th & Pearl sites are most likely to be representative of transport winds.

Wind Persistence

Our previous study of the air quality impact of SO_2 emissions from the ASARCO smelter (Cramer, et al., 1976) identified the "critical wind-speed condition" (persistent moderate-to-strong winds in combination with neutral stability) as one of the meteorological conditions conducive

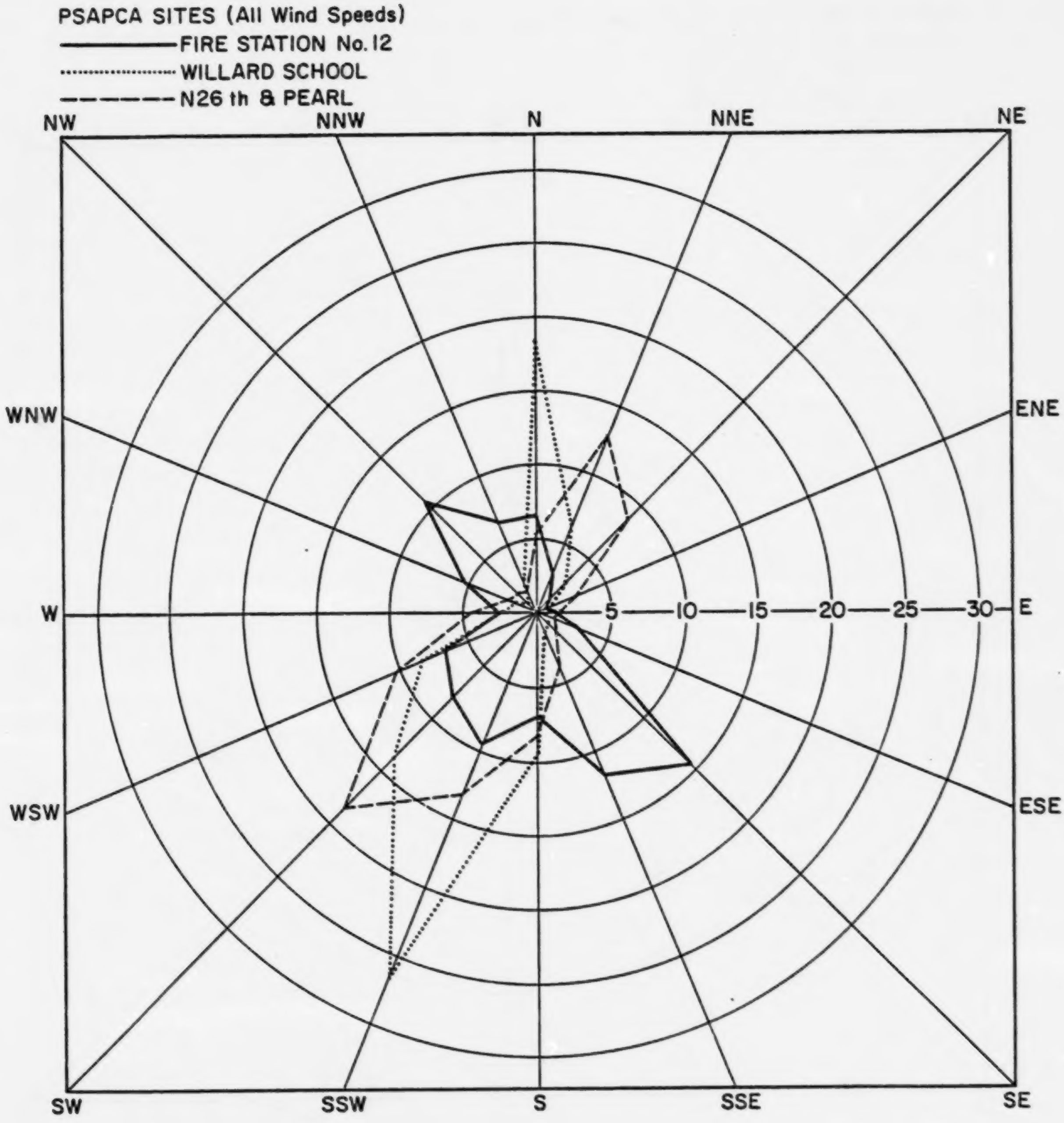

Figure 3-8. PSAPCA Fire Station No. 12, Willard School and N26th & Pearl 1981 annual wind-direction distributions for all wind speeds. Directions are directions from which the wind is blowing, and the percentage frequency scale is shown at the right center of the figure.

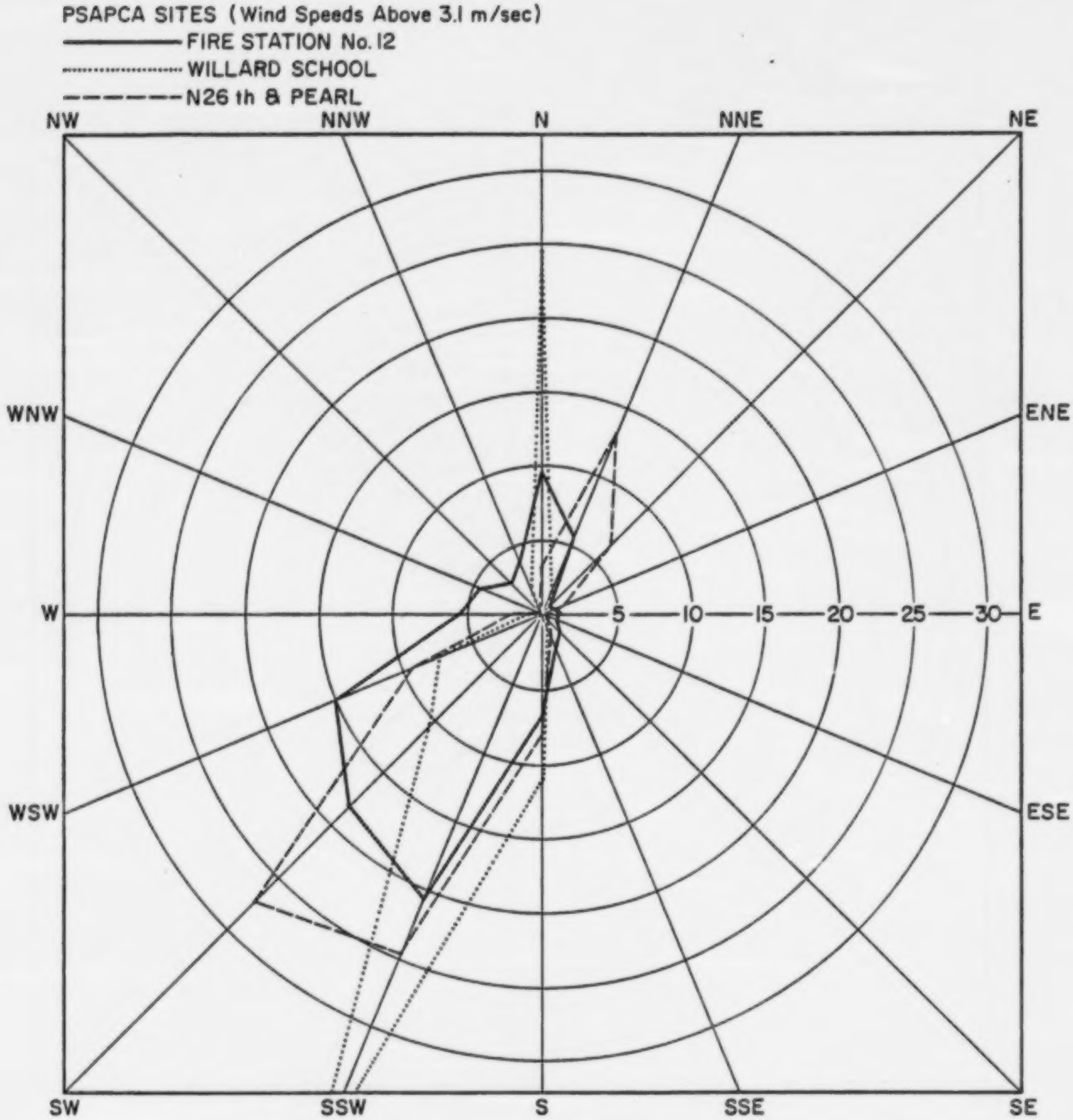

Figure 3-9. PSAPCA Fire Station No. 12, Willard School and N26th & Pearl 1981 annual wind-direction distributions for wind speeds above 3.1 meters per second. Directions are directions from which the wind is blowing, and the percentage frequency scale is shown at the right center of the figure.

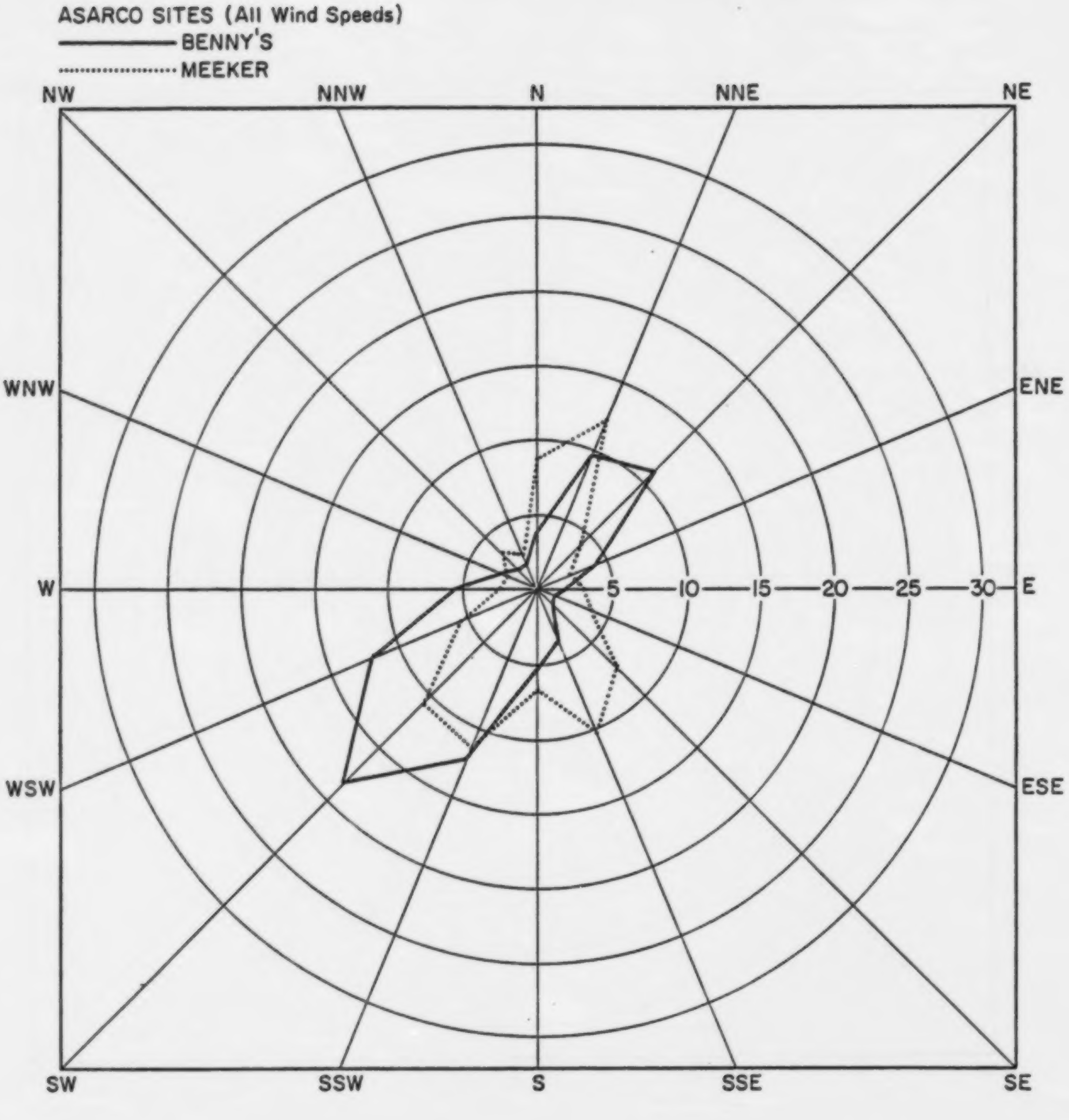

Figure 3-10. ASARCO Benny's (N26th & Pearl) and Meeker 1981 annual wind-direction distributions for all wind speeds. Directions are directions from which the wind is blowing, and the percentage frequency scale is shown at the right center of the figure.

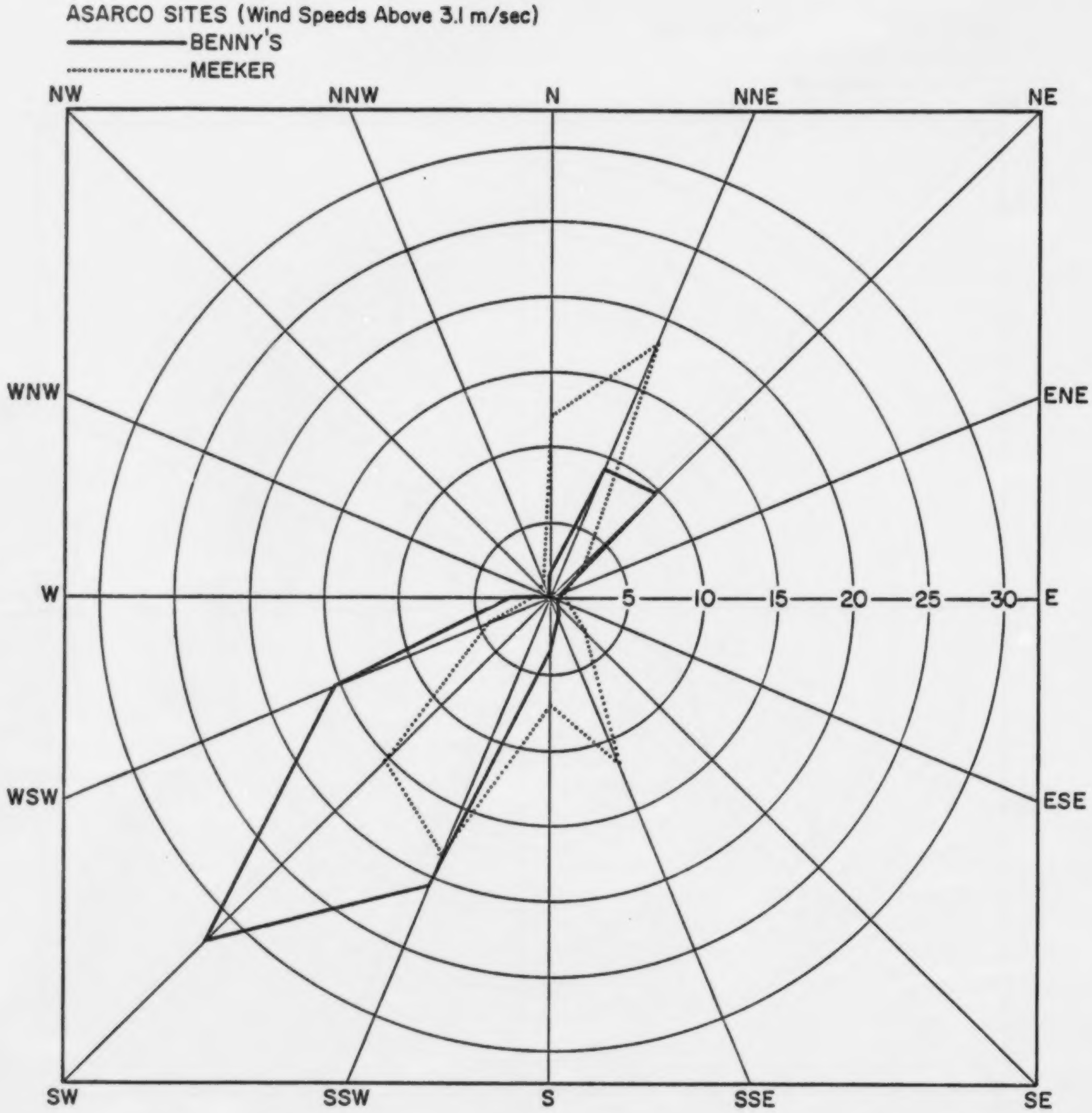

Figure 3-11. ASARCO Benny's (N26th & Pearl) and Meeker 1981 annual wind-direction distributions for wind speeds above 3.1 meters per second. Directions are directions from which the wind is blowing, and the percentage frequency scale is shown at the right center of the figure.

to the occurrence of relatively high 24-hour average ground-level concentrations attributable to buoyant stack emissions. Although it is often difficult to measure the maximum ground-level concentrations caused by the critical wind-speed condition because the areas within which the relatively high concentrations occur have narrow angular dimensions (as measured from the stack), the importance of this meteorological regime follows from simple theoretical considerations (Pasquill, 1974 and others) and is supported by SO_2 air quality data (Cramer, et al., 1975; Gorr and Dunlap, 1977; Bowers, et al., 1980; and others). Consequently, our MAQSAP analyses of the PSAPCA wind data included a search for persistent moderate-to-strong winds.

Table 3-3 lists, for each of the three PSAPCA and two ASARCO wind measurement sites considered in the MAQSAP analyses, the number of cases during 1981 when winds above 3.1 meters per second persisted within one of the sixteen standard 22.5-degree wind-direction sectors for 10 or more hours. We point out that Table 3-3 underestimates actual wind persistence within a narrow angular sector because the table does not consider cases with mean wind directions near the boundary between two standard wind-direction sectors. However, Table 3-3 provides a relative indication of the most persistent wind directions. As shown by the table, moderate-to-strong winds that persist within a narrow angular sector are most common at Willard School and Meeker Junior High School, the two sites where localized terrain channeling is most evident. The wind-direction sector with the largest number of persistent moderate-to-strong wind events is south-southwest or southwest at each site. Thus, the wind data from all of the sites indicate that an important meteorological regime for buoyant emissions from the stacks of the tideflats sources is the critical wind-speed condition with south-southwest or southwest winds. Because emissions from the proposed Kaiser and Tacoma City Light tall stacks will not mix to the surface before they reach the bluff area with south-southwest or southwest winds, relatively high 24-hour average concentrations attributable to emissions from these stacks can be expected on the bluff during periods with persistent moderate-to-strong south-southwest or southwest winds.

TABLE 3-3

NUMBER OF OCCURRENCES DURING 1981 OF WIND SPEEDS ABOVE 3.1 METERS PER SECOND PERSISTING WITHIN ANY STANDARD* 22.5-DEGREE SECTOR FOR 10 OR MORE HOURS

Season	Number of Occurrences								
	N	NNE	E	SSE	S	SSW	SW	WSW	Total
(a) PSAPCA Fire Station No. 12									
Winter	0	1	0	0	1	1	0	0	3
Spring	0	0	1	0	0	1	1	2	5
Summer	0	0	0	0	0	0	0	0	0
Fall	0	0	0	0	0	1	0	0	1
Annual	0	1	1	0	1	3	1	2	9
(b) PSAPCA Willard School									
Winter	0	0	0	0	1	7	0	0	8
Spring	5	0	0	0	0	6	1	0	12
Summer	2	0	0	0	0	1	0	0	3
Fall	1	0	0	0	0	1	0	0	2
Annual	8	0	0	0	1	15	1	0	25
(c) PSAPCA N26th & Pearl									
Winter	0	0	0	0	0	3	1	1	5
Spring	0	0	0	0	0	2	2	0	4
Summer	0	0	0	0	0	0	1	0	1
Fall	0	1	0	0	0	0	1	0	2
Annual	0	1	0	0	0	5	5	1	12
(d) ASARCO Benny's (N26th & Pearl)									
Winter	0	1	0	0	0	0	1	0	2
Spring	0	0	0	0	0	0	3	0	3
Summer	0	0	0	0	0	0	2	0	2
Fall	0	1	0	0	0	0	0	0	1
Annual	0	2	0	0	0	0	6	0	8

TABLE 3-3 (Continued)

Season	Number of Occurrences								
	N	NNE	E	SSE	S	SSW	SW	WSW	Total
(e) ASARCO Meeker Junior High School									
Winter	0	1	0	4	0	2	1	0	8
Spring	0	2	1	1	0	1	3	0	8
Summer	1	1	0	0	0	0	3	0	5
Fall	2	3	0	3	0	1	1	0	10
Annual	3	7	1	8	0	4	8	0	31

* Only the wind-direction sectors which satisfy the persistence criteria are shown.

Mixing Depths

The SHORTZ/LONGZ models define the top of the surface mixing layer as the height at which the vertical intensity of turbulence is of the order of 0.01 or smaller. That is, the depth of the surface mixing layer is a function of the vertical profile of the intensity of turbulence rather of the thermal stratification. The mixing depth is determined by a combination of solar heating (the convective component) and mechanical turbulence (the mechanical component). Because measurements of the vertical profile of the intensity of turbulence are not generally available, we normally estimate the depth of the surface mixing layer from vertical wind and temperature profiles or from acoustic sounder data. In the simplest case, the base of an elevated inversion layer is taken to be the top of the surface mixing layer. It is important to recognize that, if a surface-based inversion exists, the depth of the surface mixing layer is greater than zero because of the presence of surface roughness elements and, in industrial or urban areas, the presence of heat sources.

A major deficiency in the meteorological data available to develop inputs to the SHORTZ/LONGZ models for application to the Tacoma area is the almost complete absence of information on the depth of the surface mixing layer. The Washington DOE takes 0700 PST or PDT soundings on week days at Portage Bay in Seattle, approximately 45 kilometers north of the Tacoma tideflats area. These soundings provide useful information about conditions during the early morning hours, but caution must be exercised in extrapolating these soundings to the remainder of the day. It is our understanding that the Washington DOE also operates an acoustic sounder on a continuous basis at Portage Bay, but that the acoustic sounder data are not reduced. We believe that the acoustic sounder data could be used to estimate hourly mixing depths which would be very useful for dispersion model analyses.

Cramer, et al. (1976) analyzed the twice daily Holzworth (1972) mixing depths computed for the Seattle-Tacoma Airport during the period 1959 through 1961 to determine seasonal median early morning and afternoon mixing depths for each combination of wind-speed and time-of-day categories. The resulting median mixing depths are listed in Table 3-4. Cramer, et al. (1976) then estimated median mixing depths for the various combinations of wind-speed and Pasquill stability categories (as defined by Turner, 1964) as follows:

- The seasonal median afternoon mixing depths were averaged and assigned to the unstable A, B and C categories
- The seasonal median early morning mixing depths were averaged and assigned to the combined stable E and F categories
- The seasonal median early morning and afternoon mixing depths were averaged and assigned to the neutral D category

The resulting mixing depths, which are reproduced in Table 3-5, probably are representative of average conditions in the Tacoma area and are suitable for use in LONGZ calculations. Because of time constraints, we also used the mixing depths in Table 3-5 to develop SHORTZ hourly meteorological inputs for selected "worst-case" short-term periods (see Appendix C). However, we recommend that any mixing depths that can be estimated for these "worst-case" short-term periods from the Portage Bay soundings be substituted for the mixing depths taken from Table 3-5.

Our examination of the 0700 PST or 0700 PDT Portage Bay vertical temperature and wind profiles provided by PSAPCA (Anderson, 1982) for the four air stagnation episodes during 1981 showed that they were generally

TABLE 3-4

MEDIAN MIXING DEPTHS MEASURED AT THE SEATTLE-TACOMA AIRPORT DURING THE PERIOD 1959 THROUGH 1961*

Wind Speed (m/sec)	Median Mixing Depth (m)							
	Winter		Spring		Summer		Fall	
	Night	Afternoon	Night	Afternoon	Night	Afternoon	Night	Afternoon
0 - 1.5	125	375	125	1250	125	1250	125	625
1.6 - 3.0	125	375	375	1250	375	1250	125	875
3.1 - 5.1	375	375	675	1250	375	1250	375	875
5.2 - 8.2	625	625	875	1250	625	1250	875	875
8.3 - 10.8	625	625	1250	1250	1250	1250	875	875
> 10.8	625	625	1250	1250	1250	1250	875	875

* From Table 3-6 of the report by Cramer, et al. (1976).

TABLE 3-5

MIXING DEPTHS IN METERS*

Pasquill Stability Category	Wind Speed (m/sec)					
	0.0 - 1.5	1.6 - 3.1	3.2 - 5.1	5.2 - 8.2	8.3 - 10.8	>10.8
A	875	940	---	---	---	---
B	875	940	940	---	---	---
C	875	940	940	1000	1000	1000
D	500	595	690	875	1000	1000
E	125	250	440	---	---	---

* From Table 3-9 of the report by Cramer, et al. (1976).

characterized by strong surface-based inversions with no clear indication of the top of the surface mixing layer. One objective technique for calculating the mechanical component of the mixing depth that we consider to be suitable for use with SHORTZ is given by the Benkley and Schulman (1979) expression

$$H_m \text{ (m)} \approx 100\ \bar{u} \text{ (m/sec)} \qquad (3\text{-}1)$$

where $\bar{u}$ is the 3-hour average wind speed for the 3-hour period centered on the hour for which the mixing depth is calculated. The measurement height of $\bar{u}$ is at or near 10 meters above ground level.

3.2 REVIEW OF THE AVAILABLE SO_2 AIR QUALITY DATA

Hourly (PSAPCA) or 30-minute average (ASARCO) SO_2 air quality measurements are made at all of the wind measurement sites shown in Figure 3-1 except the PSAPCA Fire Station No. 12 and Willard School sites. Additionally, Kaiser measured hourly SO_2 concentrations at its plant during the period 4 June through 13 December 1981 and on the bluff north-northeast of the plant during all of 1981. The locations of the Kaiser Bluff site and Plant site SO_2 monitors are shown in Figure 3-1, and Table 3-6 gives the UTM coordinates and elevations of the two Kaiser monitoring sites. The only 1981 SO_2 air quality data made available to the H. E. Cramer Company on computer tape for use in this study were the PSAPCA data and the Kaiser data. The PSAPCA data were provided by PSAPCA (Knechtel, 1982) and the Kaiser data were provided by Kaiser's consultant, CH2M Hill (Caniparoli, 1982). We first used MAQSAP with the N26th & Pearl hourly wind and SO_2 concentration data as a check on our previous conclusion (Cramer, *et al.*, 1976) that the N26th & Pearl winds are the best available indicator of transport winds for emissions from the ASARCO Main Stack. We then used MAQSAP with several combinations of wind data and Kaiser SO_2 concentration data to gain insight into the winds that are most representative of transport winds for emissions from the tideflats sources.

TABLE 3-6

UNIVERSAL TRANSVERSE MERCATOR (UTM) COORDINATES AND ELEVATIONS ABOVE MEAN SEA LEVEL (MSL) OF THE KAISER BLUFF AND PLANT SITE SO_2 AIR QUALITY MONITORS

Site	Coordinates		Ground Elevation (m MSL)
	UTM X (km)	UTM Y (km)	
Kaiser Bluff Site	548.400	5,235.410	125
Kaiser Plant Site	547.575	5,234.190	3

Annual Average SO_2 Concentrations

MAQSAP uses hourly wind and SO_2 concentration measurements to determine the annual average SO_2 concentration for each combination of wind-direction and time-of-day categories. For our first set of MAQSAP analyses, we merged the hourly SO_2 concentration measurements from the PSAPCA N26th& Pearl site with the concurrent hourly wind data from: (1) the PSAPCA N26th & Pearl site, and (2) the ASARCO Benny's (N26th & Pearl) site. The 1981 annual average SO_2 concentrations at the PSAPCA N26th & Pearl site are given by PSAPCA N26th & Pearl and ASARCO Benny's (N26th & Pearl) wind directions in Tables 3-7 and 3-8, respectively. The two tables consider only the hours with valid SO_2 concentration measurements and do not attempt to account for the 660 hours of missing concentration data. As shown by the average concentrations at the bottom of each table, the highest 1981 average concentration at N26th & Pearl occurred during the afternoon and the lowest average concentration occurred at night. The average concentration for each wind direction varies, depending on the wind data used in the MAQSAP analysis. This variation is illustrated in Figure 3-12, which shows the annual pollution roses (annual average concentrations in parts per billion (ppb) for each wind-direction sector). North-northeast winds are required for the straight-line transport of ASARCO emissions to N26th & Pearl, while east and east-southeast winds are required for the straight-line transport of emissions from the tideflats sources to N26th & Pearl. As shown by Figure 3-12, the ASARCO Benny's wind directions appear to be more representative of these source-receptor relationships than the PSAPCA N26th & Pearl wind directions. However, it is important to note that the wind direction required for the straight-line transport of ASARCO emissions to N26th and Pearl is near the boundary between the standard 22.5-degree sectors for north and north-northeast winds. Consequently, an alternate interpretation of the almost identical average concentrations with north and north-northeast winds at the PSAPCA N26th & Pearl site is that the PSAPCA N26th & Pearl wind directions are more representative of transport wind directions for ASARCO emissions than are the Benny's wind directions

TABLE 3-7

1981 ANNUAL AVERAGE SO_2 CONCENTRATION AT THE PSAPCA N26TH & PEARL SITE BY PSAPCA N26TH & PEARL WIND DIRECTION

Wind Direction (Sector)	Annual Average SO_2 Concentration (ppm)				
	Night	Morning	Afternoon	Evening	Average
N	0.0210	0.0348	0.0340	0.0211	0.0287
NNE	0.0225	0.0212	0.0319	0.0313	0.0273
NE	0.0099	0.0103	0.0212	0.0095	0.0130
ENE	0.0098	0.0138	0.0138	0.0117	0.0114
E	0.0102	0.0115	0.0060	0.0207	0.0112
ESE	0.0088	0.0125	0.0071	0.0073	0.0088
SE	0.0067	0.0029	0.0010	0.0087	0.0055
SSE	0.0036	0.0029	0.0031	0.0054	0.0036
S	0.0019	0.0024	0.0025	0.0021	0.0021
SSW	0.0013	0.0009	0.0012	0.0022	0.0013
SW	0.0011	0.0018	0.0011	0.0007	0.0011
WSW	0.0011	0.0028	0.0015	0.0010	0.0015
W	0.0023	0.0040	0.0032	0.0017	0.0028
WNW	0.0050	0.0037	0.0158	0.0044	0.0124
NW	0.0033	0.0200	0.0261	0.0080	0.0190
NNW	0.0111	0.0280	0.0265	0.0050	0.0187
Average	0.0071	0.0084	0.0120	0.0106	0.0092

TABLE 3-8

1981 ANNUAL AVERAGE SO_2 CONCENTRATION AT THE PSAPCA N26TH & PEARL SITE BY ASARCO BENNY'S (N26TH & PEARL) WIND DIRECTION

Wind Direction (Sector)	Annual Average SO_2 Concentration (ppm)				
	Night	Morning	Afternoon	Evening	Average
N	0.0199	0.0239	0.0315	0.0173	0.0253
NNE	0.0258	0.0361	0.0355	0.0331	0.0318
NE	0.0125	0.0148	0.0253	0.0182	0.0172
ENE	0.0109	0.0154	0.0243	0.0152	0.0142
E	0.0121	0.0139	0.0073	0.0185	0.0127
ESE	0.0083	0.0489	0.0083	0.0062	0.0116
SE	0.0074	0.0085	0.0076	0.0080	0.0077
SSE	0.0045	0.0046	0.0031	0.0092	0.0048
S	0.0024	0.0034	0.0026	0.0030	0.0026
SSW	0.0019	0.0016	0.0018	0.0026	0.0019
SW	0.0009	0.0013	0.0012	0.0013	0.0011
WSW	0.0016	0.0024	0.0016	0.0015	0.0017
W	0.0028	0.0046	0.0069	0.0013	0.0048
WNW	0.0043	0.0067	0.0113	0.0083	0.0088
NW	0.0067	0.0150	0.0275	0.0037	0.0185
NNW	0.0092	0.0233	0.0195	0.0114	0.0150
Average	0.0071	0.0084	0.0120	0.0106	0.0092

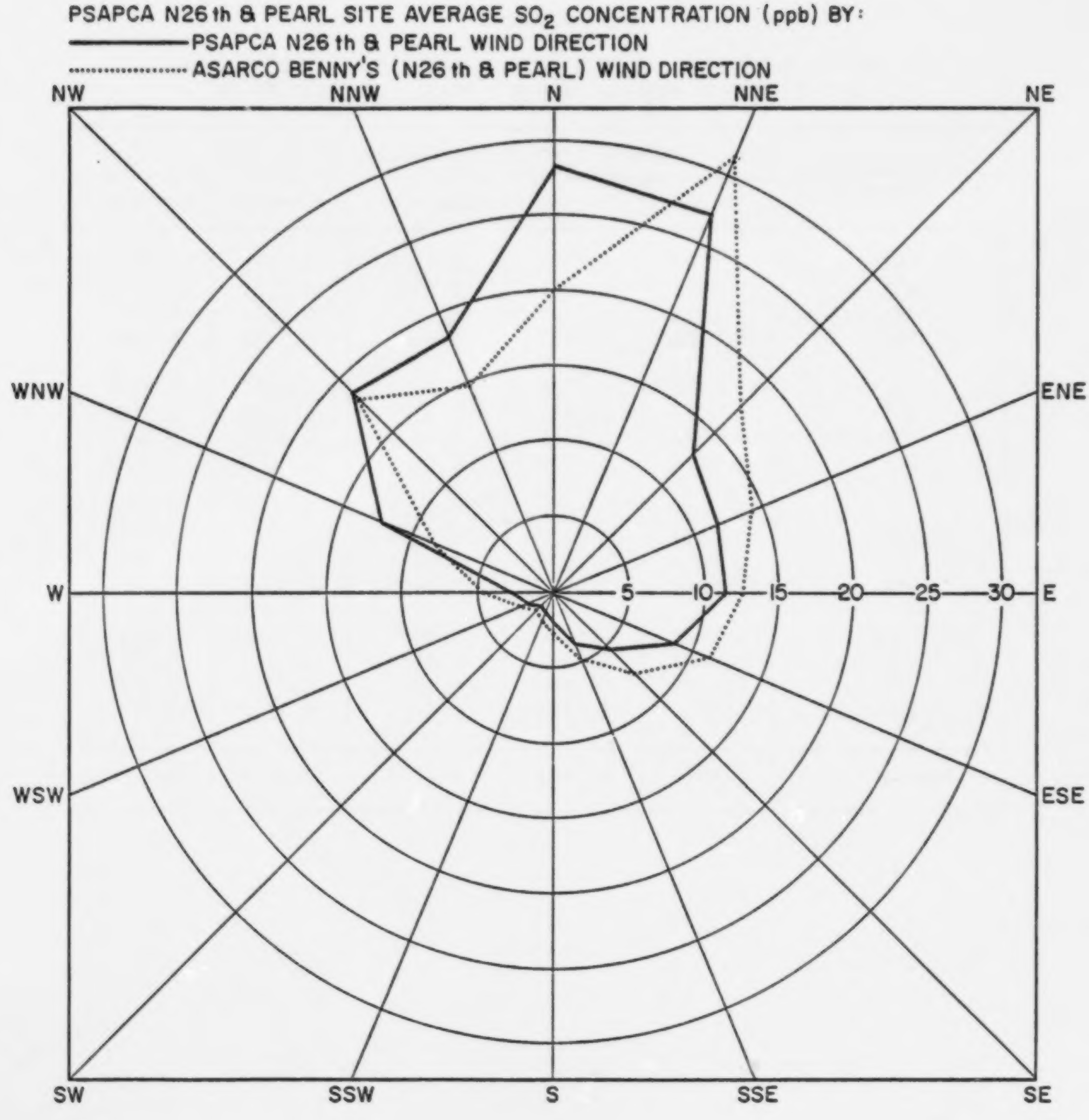

Figure 3-12. PSAPCA N26th & Pearl site 1981 average SO_2 concentrations in parts per billion (ppb) by PSAPCA N26th & Pearl and ASARCO Benny's (N26th & Pearl) wind directions. Directions are directions from which the wind is blowing, and the concentration scale in ppb is shown at the right center of the figure.

(Carson, 1982). An unexpected result shown in Figure 3-12 is that the average of the hourly concentrations measured at N26th & Pearl during the hours when northwest winds were measured by either of the two N26th & Pearl wind sensors exceeds the average concentrations when east and eastsoutheast winds were measured. Because we know of no significant SO_2 source northwest of N26th & Pearl, we do not have any simple explanation for the occurrence of a high average concentration with northwest winds.

It is important to note that the differences in the two N26th & Pearl site pollution roses developed using the PSAPCA N26th & Pearl and ASARCO Benny's (N26th & Pearl) wind data (see Figure 3-12) are much larger than the differences in the annual wind-direction distributions shown in Figure 3-6. We conclude from this result that, although there is a close average correspondence between the two N26th & Pearl wind-direction measurements, there often are appreciable differences between the concurrent hourly wind directions.

To evaluate the representativeness of the ASARCO Benny's (N26th & Pearl) and Meeker winds of transport winds in the tideflats area, we merged these winds with the concurrent Kaiser Bluff site hourly SO_2 concentrations for use in our second set of MAQSAP analyses. The 1981 annual average SO_2 concentrations at the Kaiser Bluff site are given by ASARCO Benny's (N26th & Pearl) and ASARCO Meeker wind directions in Tables 3-9 and 3-10, respectively. Unlike the average concentrations by time-of-day category at N26th & Pearl, the average concentrations at the bottoms of Tables 3-9 and 3-10 show that there is essentially no diurnal variation in average concentration at the Bluff site. The Bluff site pollution roses shown in Figure 3-13 also reveal unexpected features. West-northwest winds are required for the straight-line transport to the Bluff site of ASARCO emissions, while south-southwest through west-southwest winds are required for the straight-line transport to the Bluff site of emissions from the tideflats sources. The pollution roses developed using the ASARCO Benny's and Meeker wind data both show the expected influence of ASARCO emissions during hours with west-northwest winds. Also, the pollution rose based on the Meeker

TABLE 3-9

1981 ANNUAL AVERAGE SO_2 CONCENTRATION AT THE KAISER BLUFF SITE BY ASARCO BENNY'S (N26TH & PEARL) WIND DIRECTION

Wind Direction (Sector)	Annual Average SO_2 Concentration (ppm)				
	Night	Morning	Afternoon	Evening	Average
N	0.0093	0.0149	0.0066	0.0046	0.0079
NNE	0.0055	0.0108	0.0051	0.0052	0.0058
NE	0.0059	0.0076	0.0056	0.0055	0.0061
ENE	0.0044	0.0074	0.0086	0.0110	0.0064
E	0.0043	0.0093	0.0048	0.0067	0.0053
ESE	0.0060	0.0155	0.0085	0.0076	0.0067
SE	0.0063	0.0016	0.0070	0.0101	0.0064
SSE	0.0056	0.0067	0.0055	0.0094	0.0060
S	0.0058	0.0057	0.0070	0.0060	0.0060
SSW	0.0059	0.0067	0.0072	0.0076	0.0065
SW	0.0097	0.0094	0.0083	0.0082	0.0090
WSW	0.0102	0.0147	0.0088	0.0083	0.0096
W	0.0160	0.0187	0.0159	0.0106	0.0158
WNW	0.0171	0.0160	0.0205	0.0112	0.0182
NW	0.0091	0.0157	0.0175	0.0163	0.0154
NNW	0.0109	0.0182	0.0097	0.0108	0.0115
Average	0.0086	0.0102	0.0091	0.0086	0.0090

TABLE 3-10

1981 ANNUAL AVERAGE SO_2 CONCENTRATION AT THE KAISER BLUFF SITE BY ASARCO MEEKER WIND DIRECTION

Wind Direction (Sector)	Annual Average SO_2 Concentration (ppm)				
	Night	Morning	Afternoon	Evening	Average
N	0.0074	0.0093	0.0055	0.0094	0.0070
NNE	0.0664	0.0062	0.0052	0.0056	0.0058
NE	0.0094	0.0070	0.0092	0.0106	0.0094
ENE	0.0121	0.0085	0.0057	0.0188	0.0127
E	0.0132	0.0101	0.0061	0.0091	0.0119
ESE	0.0157	0.0101	0.0065	0.0118	0.0146
SE	0.0086	0.0100	0.0107	0.0142	0.0094
SSE	0.0055	0.0095	0.0075	0.0061	0.0066
S	0.0065	0.0105	0.0096	0.0067	0.0083
SSW	0.0092	0.0112	0.0106	0.0102	0.0101
SW	0.0084	0.0099	0.0070	0.0054	0.0075
WSW	0.0081	0.0131	0.0077	0.0079	0.0085
W	0.0060	0.0156	0.0128	0.0059	0.0114
WNW	0.0122	0.0142	0.0192	0.0060	0.0171
NW	0.0099	0.0128	0.0159	0.0179	0.0149
NNW	0.0082	0.0133	0.0099	0.0062	0.0096
Average	0.0086	0.0102	0.0091	0.0086	0.0090

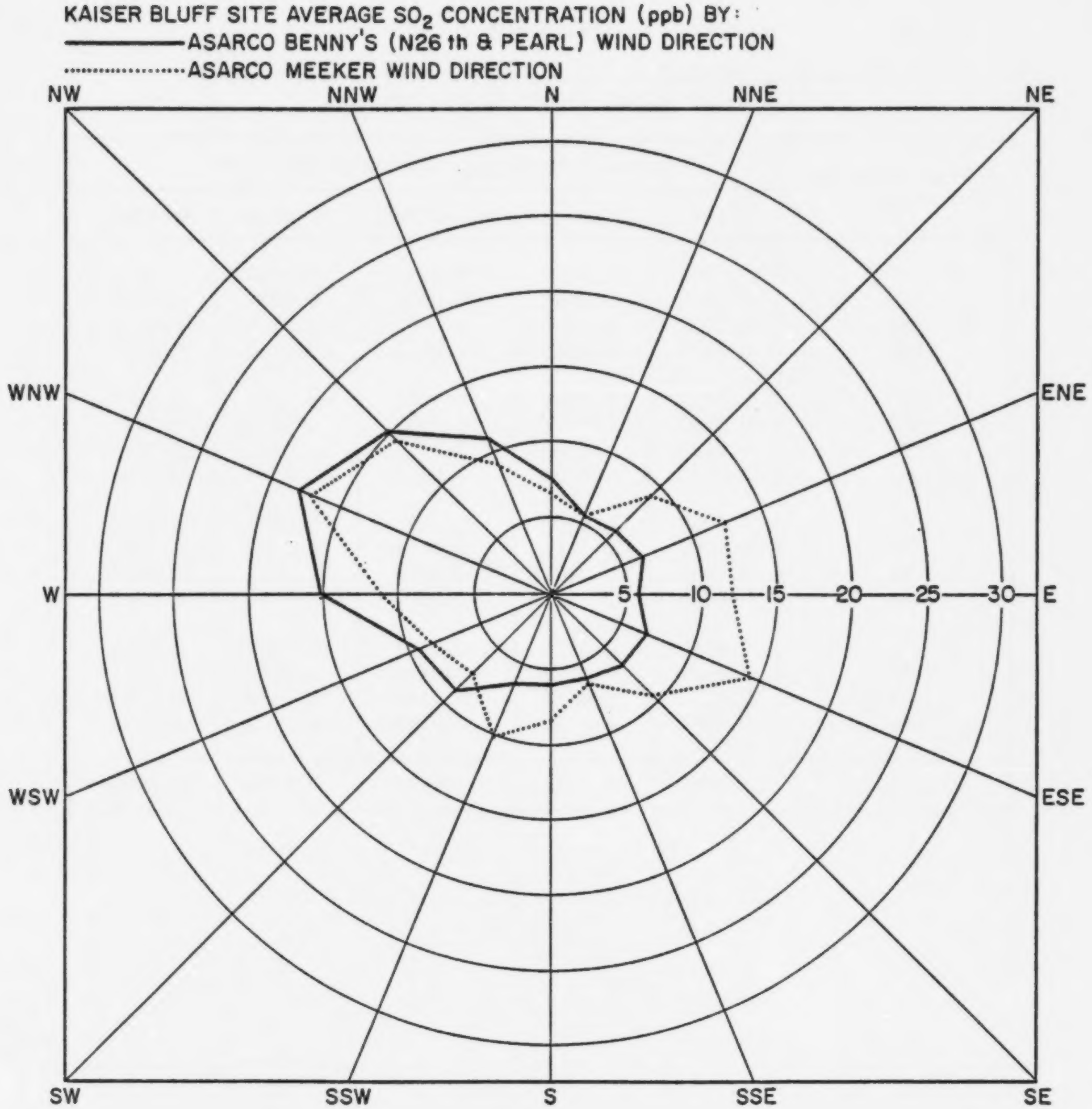

Figure 3-13. Kaiser Bluff site 1981 average SO_2 concentrations in parts per billion (ppb) by ASARCO Benny's (N26th & Pearl) and Meeker wind directions. Directions are directions from which the wind is blowing, and the concentration scale in ppb is shown at the right center of the figure.

wind data shows a peak with south-southwest winds that may be attributable to emissions from the Kaiser plant. However, the pollution rose based on the Meeker wind data shows unexpected high average concentrations associated with winds from the northeast through southeast. We do not know of any SO_2 sources in the sector northeast through southeast of the Bluff site that can account for these relatively high average concentrations. One hypothesis to explain the occurrence of relatively high average concentrations with easterly winds at the Meeker site is that SO_2 previously emitted by one or more of the sources in or adjacent to the tideflats area (for example, the ASARCO smelter) are advected back over the Bluff site following a wind shift.

Our third set of MAQSAP analyses merged the hourly SO_2 concentrations from the Kaiser Plant site with the concurrent hourly wind data from: (1) the PSAPCA Fire Station No. 12 site, and (2) the ASARCO Benny's (N26th & Pearl) site. The 1981 annual average SO_2 concentrations at the Kaiser Plant site are given by PSAPCA Fire Station No. 12 and ASARCO Benny's (N26th & Pearl) wind directions in Tables 3-11 and 3-12, respectively. As shown by the average concentrations at the bottom of each table, there are no clear diurnal trends. Assuming the average Plant site concentration for the approximate 6-month period of record to be representative of an annual average concentration, the Plant site annual average concentration of 0.0186 ppm is approximately double the annual average concentrations at the PSAPCA N26th & Pearl site and the Kaiser Bluff site. Also, the average concentration at the Plant site is very near the PSAPCA and Washington State annual ambient air quality standard of 0.02 ppm. The Plant site pollution roses based on the Fire Station No. 12 and Benny's wind data are shown in Figure 3-14. (We point out that the scale of Figure 3-14 differs from the scale used in Figures 3-12 and 3-13 because of the much higher average concentrations at the Plant site.) The dry scrubber system stacks of Kaiser Line 4 are about 200 meters south of the Plant site monitor, and both pollution roses show the expected high average concentration with south winds. Both pollution roses also show the expected presence of ASARCO emissions with west-northwest winds. However, both pollution roses show average concentrations with winds from the east through south-southeast that are

TABLE 3-11

1981 ANNUAL AVERAGE SO_2 CONCENTRATION AT THE KAISER PLANT SITE BY PSAPCA FIRE STATION NO. 12 WIND DIRECTION

Wind Direction (Sector)	Annual Average SO_2 Concentration* (ppm)				
	Night	Morning	Afternoon	Evening	Average
N	0.0107	0.0132	0.0124	0.0115	0.0121
NNE	0.0097	0.0091	0.0108	0.0098	0.0099
NE	0.0119	0.0097	0.0105	0.0153	0.0120
ENE	0.0116	0.0193	0.0380	0.0080	0.0136
E	0.0199	0.0210	0.0168	0.0246	0.0204
ESE	0.0244	0.0243	0.0158	0.0255	0.0237
SE	0.0200	0.0209	0.0309	0.0334	0.0218
SSE	0.0230	0.0199	0.0326	0.0331	0.0247
S	0.0473	0.0658	0.0474	0.0511	0.0513
SSW	0.0341	0.0322	0.0370	0.0417	0.0355
SW	0.0109	0.0112	0.0117	0.0090	0.0110
WSW	0.0094	0.0096	0.0073	0.0077	0.0082
W	0.0072	0.0083	0.0068	0.0060	0.0068
WNW	0.0069	0.0261	0.0117	0.0100	0.0115
NW	0.0078	0.0157	0.0176	0.0098	0.0142
NNW	0.0075	0.0133	0.0162	0.0096	0.0139
Average	0.0185	0.0224	0.0172	0.0188	0.0186

* The period of record for the SO_2 concentrtation measurements is 1400 PST on 4 June through 2400 PST on 13 December.

TABLE 3-12

1981 ANNUAL AVERAGE SO_2 CONCENTRATION AT THE KAISER PLANT SITE SITE BY ASARCO BENNY'S (N26TH & PEARL) WIND DIRECTION

Wind Direction (Sector)	Annual Average SO_2 Concentration* (ppm)				
	Night	Morning	Afternoon	Evening	Average
N	0.0099	0.0194	0.0103	0.0087	0.0103
NNE	0.0122	0.0213	0.0106	0.0100	0.0118
NE	0.0131	0.0181	0.0117	0.0088	0.0131
ENE	0.0167	0.0201	0.0223	0.0142	0.0180
E	0.0185	0.0310	0.0252	0.0189	0.0207
ESE	0.0201	0.0335	0.0286	0.0383	0.0259
SE	0.0198	0.0267	0.0329	0.0222	0.0234
SSE	0.0225	0.0204	0.0280	0.0322	0.0240
S	0.0279	0.0464	0.0384	0.0421	0.0338
SSW	0.0333	0.0403	0.0409	0.0468	0.0373
SW	0.0168	0.0142	0.0142	0.0140	0.0151
WSW	0.0099	0.0126	0.0134	0.0105	0.0122
W	0.0097	0.0144	0.0224	0.0133	0.0169
WNW	0.0118	0.0204	0.0250	0.0108	0.0204
NW	0.0100	0.0180	0.0190	0.0144	0.0164
NNW	0.0106	0.0200	0.0134	0.0098	0.0121
Average	0.0185	0.0224	0.0172	0.0188	0.0186

* The period of record for the SO_2 concentration measurements is 1400 PST on 4 June through 2400 PST on 13 December.

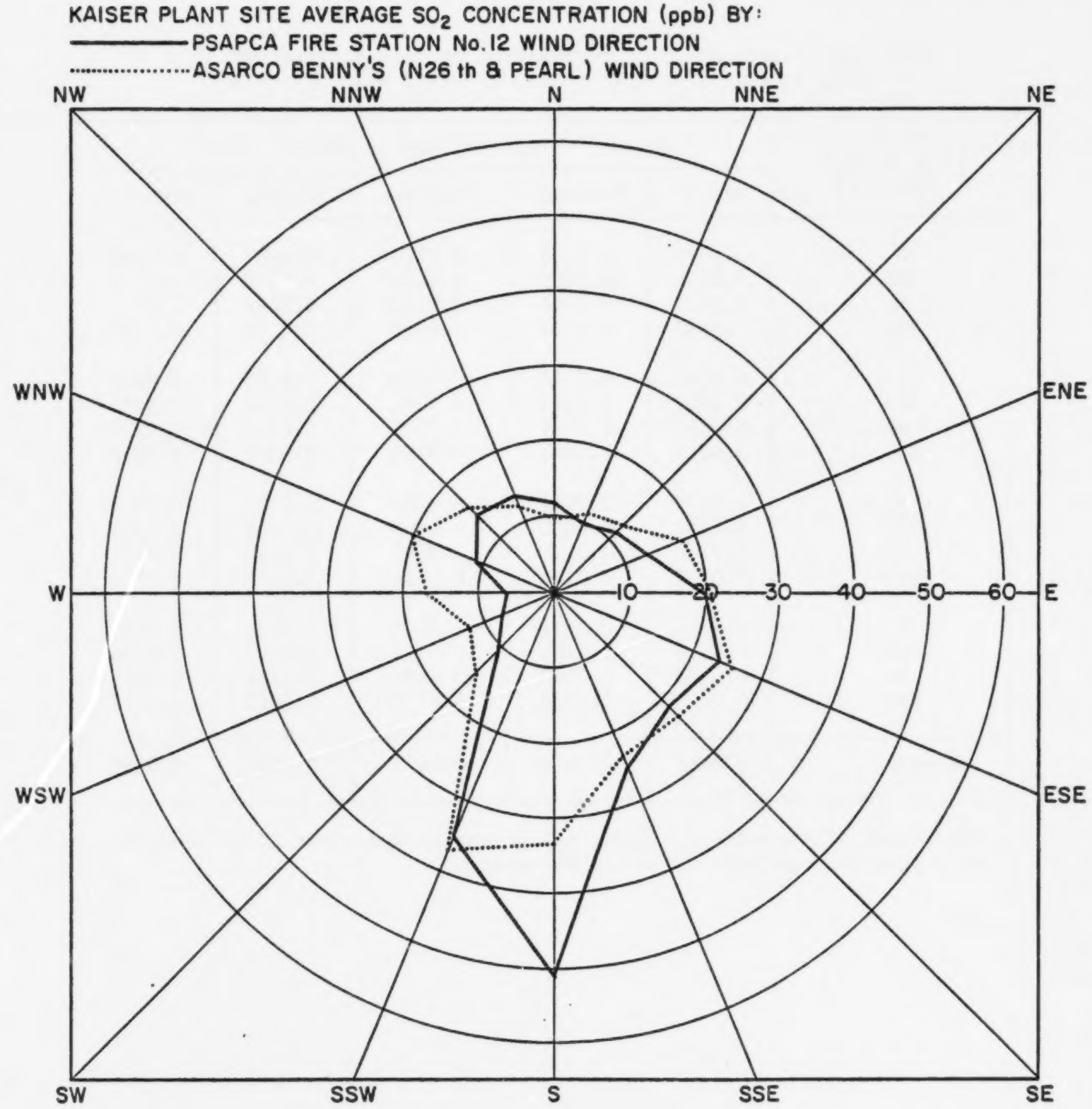

Figure 3-14. Kaiser Plant site 1981 average SO_2 concentrations in parts per billion (ppb) by PSAPCA Fire Station No. 12 and ASARCO Benny's (N26th & Pearl) wind directions. Directions are directions from which the wind is blowing, and the concentration scale in ppb is shown at the right center of the figure. Note that the scale of this figure differs from the scale of Figures 3-12 and 3-13.

higher than the average concentrations with winds from the west-northwest. Roof monitor emissions from Kaiser Line 4 and/or from the dry scrubber stacks of Lines 1 and 2 may be the cause of the relatively high average concentrations at the plant site that are associated with hours of easterly winds over the tideflats area.

Hourly SO_2 Concentrations

Table 3-13 lists the number of 1981 occurrences at the PSAPCA N26th & Pearl site of hourly SO_2 concentrations above 0.10 ppm, classified by time of day and PSAPCA N26th & Pearl and ASARCO Benny's (N26th & Pearl) wind directions. Approximately 60 percent of the 92 cases occurred during the afternoon time-of-day category, 18 percent occurred during the night time-of-day category and 11 percent occurred during each of the transition (morning and evening) time-of-day categories. Also, over 70 percent of the cases occurred during hours when the PSAPCA N26th & Pearl and ASARCO Benny's wind directions were north to northeast. These results strongly suggest that emissions from the ASARCO smelter are principally responsible for the occurrence of the highest hourly SO_2 concentrations in the residential area of the Tacoma peninsula. If the PSAPCA N26th & Pearl wind directions are assumed to be representative of transport wind directions, only one of the 92 cases can be attributed to emissions from the tideflats sources, which are located to the east and east-southeast. Similarly, if the ASARCO Benny's wind directions are assumed to be representative of transport wind directions, only two of the cases can be attributed to emissions from the tideflats sources. However, the wind speeds for these easterly wind cases were so low (on the order of 1 meter per second) that the reported PSAPCA and ASARCO wind directions are not necessarily representative of the transport wind directions. It is of interest to note that the peak in the N26th & Pearl pollution rose with northwest winds (see Figure 3-12) is also reflected by the number of hourly concentrations above 0.10 ppm.

We conclude from the almost complete absence of hourly concentrations above 0.10 ppm associated with the wind directions required to transport emissions from the tideflats sources to the N26th & Pearl site that these

TABLE 3-13

NUMBER OF 1981 OCCURRENCES AT THE PSAPCA N26TH & PEARL SITE OF HOURLY SO_2 CONCENTRATIONS ABOVE 0.10 PPM BY PSAPCA N26TH & PEARL AND ASARCO BENNY'S (N26TH & PEARL) WIND DIRECTIONS

Wind Direction (Sector)	No. of Hourly Concentrations Above 0.10 ppm									
	Night		Morning		Afternoon		Evening		Total	
	PSAPCA N26th & Pearl	ASARCO Benny's	PSAPCA N26th & Pearl	ASARCO Benny's	PSAPCA N26th & Pearl	ASARCO Benny's	PSAPCA N26th & Pearl	ASARCO Benny's	PSACPA N26th & Pearl	ASARCO Benny's
N	4	2	2	0	15	12	1	0	22	14
NNE	7	5	2	5	18	20	8	7	35	37
NE	1	2	1	2	6	10	0	2	8	16
ENE	0	2	0	1	0	2	0	0	0	5
E	0	0	0	0	0	0	1	1	1	1
ESE	0	0	0	1	0	0	0	0	0	1
SE	0	0	0	0	0	0	0	0	0	0
SSE	0	0	0	0	0	0	0	0	0	0
S	0	0	0	0	0	0	0	0	0	0
SSW	0	1	0	0	0	0	0	0	0	1
SW	0	0	0	0	0	0	0	0	0	0
WSW	0	0	0	0	0	0	0	0	0	0
W	0	0	0	0	0	3	0	0	0	3
WNW	0	0	0	0	3	2	0	0	3	2
NW	0	0	1	0	4	6	0	0	5	6
NNW	0	0	0	1	1	0	0	0	1	1
Calm or Msg Winds	5	5	4	0	8	0	0	0	17	5
Total	17	17	10	10	55	55	10	10	92	92

emissions rarely, if ever, cause relatively high short-term SO_2 concentrations on the elevated terrain of the Tacoma peninsula. This conclusion is supported by the PSAPCA air quality measurements made during the period 1 July through 23 November 1980 when the ASARCO smelter was closed by a strike. PSAPCA reviewed the air quality data from the PSAPCA monitors at N26th & Pearl, N37th & Vassault (southwest of the ASARCO smelter), Maury Island (north-northeast of the ASARCO smelter) and Federal Way and found that (Knechtel, 1982):

> During the period ASARCO was not in operation, only 1 hour exceeding 0.05 ppm at any of the four stations was located. This was a value of 0.06 ppm at North 26th and Pearl accompanied by easterly winds.

Table 3-14 lists the number of 1981 occurrences at the Kaiser Bluff site of hourly SO_2 concentrations above 0.10 ppm, classified by time of day and ASARCO Benny's (N26th & Pearl) and Meeker wind directions. During our examination of the Kaiser Bluff site concentration data, we noted that an hourly concentration of 0.16 ppm was reported at 2100 PST on each day of the period 3 through 9 March 1981. These seven concentrations above 0.10 ppm are not included in Table 3-14 because we believe they reflect calibration checks which were inadvertently included as valid data. In contrast to the N26th & Pearl results, Table 3-14 shows that 61 percent of the 28 cases remaining after the deletion of the invalid cases occurred during the night time-of-day category, 21 percent of the cases occurred during the evening time-of-day category and 18 percent of the cases occurred during the afternoon time-of-day category. According to Table 3-14, hourly concentrations above 0.10 ppm at the Bluff site are most frequently associated with calm, missing or variable winds at the ASARCO Benny's site and with light winds from the east through east-southeast at the ASARCO Meeker site. Table 3-14 does not provide any indication that the highest short-term concentrations at the Bluff site are caused by the approximate straight-line transport of emissions from ASARCO, Kaiser or any of the other tideflats sources if the ASARCO Meeker winds are assumed to be representative of transport winds. However, all but one of the cases without calm or missing

TABLE 3-14

NUMBER OF 1981 OCCURRENCES AT THE KAISER BLUFF SITE OF HOURLY SO_2 CONCENTRATIONS ABOVE 0.10 PPM BY ASARCO BENNY'S (N26TH & PEARL) AND MEEKER WIND DIRECTIONS

Wind Direction (Sector)	No. of Hourly Concentrations Above 0.10 ppm									
	Night		Morning		Afternoon		Evening		Total	
	ASARCO Benny's	ASARCO Meeker	ASARCO Benny's	ASARCO Meeker	ASARCO Benny's	ASARCO Meeker	ASARCO Benny's	ASARCO Meeker	ASARCO Benny's	ASARCO Meeker
N	0	0	0	0	0	0	0	2	0	2
NNE	0	1	0	0	0	0	0	0	0	1
NE	0	0	0	0	0	0	0	2	0	2
ENE	0	2	0	0	0	0	1	1	1	3
E	0	3	0	0	0	0	0	0	0	3
ESE	0	8	0	0	0	0	0	0	0	8
SE	0	2	0	0	0	0	0	1	0	3
SSE	0	0	0	0	0	0	0	0	0	0
S	0	0	0	0	0	0	0	0	0	0
SSW	0	0	0	0	0	0	0	0	0	0
SW	2	0	0	0	0	0	0	0	2	0
WSW	2	0	0	0	0	0	1	0	3	0
W	2	0	0	0	2	0	0	0	4	0
WNW	0	0	0	0	2	3	0	0	2	3
NW	0	0	0	0	1	2	1	0	2	2
NNW	0	1	0	0	0	0	1	0	1	1
Calm or Msg Winds	11	0	0	0	0	0	2	0	13	0
Total	17	17	0	0	5	5	6	0	28	28

winds at the ASARCO Benny's site are associated with very light westerly winds, and these cases are possibly attributable to emissions from ASARCO and the sources within the tideflats.

Table 3-15 lists the number of 1981 occurrences at the Kaiser Plant site of hourly SO_2 concentrations above 0.10 ppm, classified by time of day and PSAPCA Fire Station No. 12 and ASARCO Benny's (N26th & Pearl) wind directions. The 43 cases are equally distributed among the four time-of-day categories. Approximately 84 percent of the cases are associated with south or south-southwest winds at Fire Station No. 12 and Benny's. The Kaiser Plant site SO_2 monitor is located on the plant property due north of the dry scrubber stacks for Kaiser Line 4. Assuming the majority of the hourly concentrations above 0.10 ppm at the Plant site to be attributable to emissions from these stacks, the results presented in Table 3-15 suggest that the Fire Station No. 12 wind directions may be more representative of the winds in the vicinity of the Kaiser plant during periods of southerly flow than are the Benny's winds. Only four of the 43 cases occurred with Benny's winds from the west through northwest, the directions required for the straight-line transport of emissions from ASARCO and the sources within the tideflats to the Plant site monitor. Although the hours with east-southeast winds at Fire Station No. 12 and Benny's are associated with a relatively high annual average concentration at the Kaiser Plant site, Table 3-15 shows that the concentrations during these hours are all less than 0.10 ppm.

3.3 EXAMINATION OF SELECTED SHORT-TERM PERIODS

The focus of our evaluation of concurrent meteorological, emissions and SO_2 air quality data was placed on cases when emissions from sources within the tideflats (rather than emissions from the ASARCO smelter) are most likely to have affected the observed SO_2 concentrations. The air quality monitors most likely to measure SO_2 concentrations attributable to emissions from the sources within the tideflats are the Kaiser Plant and

TABLE 3-15

NUMBER OF 1981 OCCURRENCES AT THE KAISER PLANT SITE OF HOURLY SO_2 CONCENTRATIONS ABOVE 0.10 PPM BY PSAPCA FIRE STATION NO. 12 AND ASARCO BENNY'S (N26TH & PEARL) WIND DIRECTIONS

Wind Direction (Sector)	No. of Hourly Concentrations Above 0.10 ppm*									
	Night		Morning		Afternoon		Evening		Total	
	PSAPCA Fire Stn. 12	ASARCO Benny's	PSAPCA Fire Stn. 12	ASARCO Benny's	PSAPCA Fire Stn. 12	ASARCO Benny's	PSAPCA Fire Stn. 12	ASARCO Benny's	PSACPA Fire Stn. 12	ASARCO Benny's
N	0	0	0	0	0	0	0	0	0	0
NNE	0	0	0	0	0	0	0	0	0	0
NE	0	0	0	0	0	0	0	0	0	0
ENE	0	0	0	0	0	0	0	0	0	0
E	0	0	0	0	0	0	0	0	0	0
ESE	0	0	0	0	0	0	0	0	0	0
SE	0	0	0	0	0	0	0	0	0	0
SSE	0	0	0	0	0	0	0	0	0	0
S	9	3	10	6	2	1	6	3	27	13
SSW	1	7	1	5	5	5	2	6	9	23
SW	0	1	0	0	0	1	0	0	0	2
WSW	1	0	0	0	0	0	0	1	1	1
W	0	0	0	0	0	2	0	0	0	2
WNW	0	0	0	0	0	1	0	0	0	1
NW	0	0	0	0	1	1	0	0	1	1
NNW	0	0	0	0	2	0	0	0	2	0
Calm or Msg Winds	0	0	0	0	1	0	2	0	3	0
Total	11	11	11	11	11	11	10	10	43	43

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* The period of record for the SO_2 concentration measurements is 1400 PST on 4 June through 2400 PST on 13 December.

Bluff sites and, to a lesser extent, the ASARCO Meeker site. Although time constraints prevented the completion of this task, our analysis partially answered the following questions:

1. For the existing sources, are the SO_2 concentrations calculated by SHORTZ at the Kaiser Bluff site during hours of moderate or strong south-southwest winds consistent with the observed concentrations?

2. For the existing sources, are the SO_2 concentrations calculated by SHORTZ at the Kaiser Plant site during hours of moderate or strong south and south-southwest winds consistent with the observed concentrations?

Additionally, at the specific request of PSAPCA, we reviewed the meteorological, emissions and air quality data available for each 1981 "air stagnation episode" (each period during 1981 for which the National Weather Service issued an Air Stagnation Advisory). Our review of the air stagnation episodes included trial SHORTZ calculations as well as a trial calculation with LONGZ as an air stagnation fumigation model (see Section 4.1 of Cramer, et al., 1976).

Kaiser Bluff Site

As noted in Section 3.2, the highest hourly SO_2 concentrations measured at the Kaiser Bluff site occur during the night, evening or afternoon time-of-day categories with very light winds. The ASARCO Meeker wind directions during these hours are almost always from the northeast through the southeast, while the ASARCO Benny's (N26th & Pearl) winds do not show any clear trends. The wind speeds during and before these hours are so light that the available wind directions generally cannot be expected to be reliable indicators of transport wind directions within the surface mixing layer. We hypothesize that these isolated 1-hour to 4-hour periods of relatively high hourly SO_2 concentrations (concentrations greater than or equal to 0.15 ppm) are attributable to previously emitted emissions which are advected back over the area following a wind shift. These emissions could come from any source or combination of sources, but the magnitude of the ASARCO stack emissions in comparison with the magnitude of the emissions from the other sources suggests that the ASARCO stack emissions are the most probable cause. Because of the light wind speeds during the hours before the hours with the highest hourly concentrations at the Bluff site, we point out that the emissions which cause these concentrations may have been emitted 12 or more hours before the onset of the high observed concentrations.

Our analysis of the meteorological data discussed in Section 3.1 suggests that the highest 24-hour average SO_2 concentrations attributable to Kaiser's potential emissions from the currently unused 152-meter stack are likely to occur on the bluff during periods of persistent moderate-to-strong south-southwest or southwest winds. However, because of the short heights of the Kaiser stacks in current use, we would expect relatively low hourly concentrations at the Bluff site under these meteorological conditions. We used our persistence search (PRSIST) data analysis program with the 1981 ASARCO Benny's (N26th & Pearl) wind data to isolate all periods when winds above 3.1 meters per second persisted within any 25-degree sector for 6 or more hours. We then examined the Kaiser Bluff site SO_2 concentration data for the south-southwest and southwest wind cases and found that the observed hourly concentrations varied from zero to about 0.03 ppm. Finally, we used SHORTZ with the 1981 average emissions parameters given in Section 2 and with hourly meteorological inputs developed following the procedures outlined in Section 5 to calculate hourly SO_2 concentrations at the Bluff site for 30 March 1981.

Table 3-16 compares the calculated and observed hourly SO_2 concentrations at the Kaiser Bluff site on 30 March 1981. The hour-to-hour correspondence between the observed and calculated concentrations is poor, a result that is expected because of the extreme sensitivity of hourly concentrations calculated at fixed locations to slight uncertainties in the transport wind direction (see Appendix E of Cramer, et al., 1976). However,

TABLE 3-16

COMPARISON OF OBSERVED AND CALCULATED SO_2 CONCENTRATIONS AT THE KAISER BLUFF SITE ON 30 MARCH 1981

Hour (PST)	SO_2 Concentration (ppm)		Ratio of Calculated and Observed Concentrations	Difference Between Observed and Calculated Concentrations (ppm)
	Observed	Calculated		
0100	0.01	0.00	0.00	0.01
0200	0.01	0.00	0.00	0.01
0300	0.03	0.00	0.00	0.03
0400	0.03	0.00	0.00	0.03
0500	0.02	0.00	0.00	0.02
0600	0.01	0.00	0.00	0.01
0700	0.03	0.03	1.00	0.00
0800	0.02	0.00	0.00	0.02
0900	0.02	0.07	3.50	-0.05
1000	0.01	0.07	7.00	-0.06
1100	0.01	0.05	5.00	-0.04
1200	0.00	0.10	∞	-0.10
1300	0.01	0.06	6.00	-0.05
1400	0.02	0.00	0.00	0.02
1500	0.02	0.06	3.00	-0.04
1600	0.01	0.04	4.00	-0.03
1700	0.00	0.00	0.00	0.00
1800	0.00	0.03	∞	0.00
1900	MSG	0.02	--	--
2000	MSG	0.11	--	--
2100	MSG	0.03	--	--
2200	0.00	0.03	∞	0.03
2300	0.00	0.05	∞	0.05
2400	0.00	0.00	0.00	0.00
Average	0.012	0.031	2.58	0.019

it should be noted that the observed and calculated hourly SO_2 concentrations are also relatively small. For example, the maximum difference between observed and calculated hourly concentrations paired in space and time is only 0.10 ppm. It is also important to note that the observed 24-hour average concentration on 30 March of 0.012 ppm is a factor of 7.3 lower than the highest 24-hour running mean concentration of 0.082 ppm (24-hour period ending at 0100 PST on 3 November 1981). We conclude that: (1) The ASARCO Benny's winds are not necessarily representative of the winds affecting the initial transport and dispersion of emissions from the existing Kaiser sources during periods of persistent moderate-to-strong south-southwest winds; and, (2) The hourly and 24-hour average concentrations calculated for the Bluff site during periods of persistent moderate-to-strong south-southwest winds are lower than the hourly and 24-hour average concentrations that occur at these sites under other meteorological conditions. For these reasons, we believe that caution should be exercised in interpreting the concentrations calculated on the elevated terrain of the bluff for emissions from the tideflats sources with short stacks. Based on our previous experience in testing SHORTZ (for example, Bowers, *et al.*, 1980), we believe that the concentrations calculated on the bluff for emissions from the Kaiser and Tacoma City Light tall stacks are more likely to be representative of actual concentrations than the concentrations calculated for emissions from the short stacks.

Kaiser Plant Site

The analysis of meteorological and air quality data discussed in Section 3.2 indicates that the highest hourly concentrations at the Kaiser Plant site occur with winds from the south or south-southwest. We selected 10 December 1981 to test SHORTZ at the plant site for two reasons. First, hourly concentrations above 0.10 ppm were measured at the Plant site during 6 of the 22 hours for which concentration measurements are available. Second, moderate-to-strong south to south-southwest winds persisted throughout the day at the ASARCO Benny's (N26th & Pearl) and PSAPCA Fire Station No. 12 sites. These wind directions suggest that the hourly SO_2 concentrations measured at the Kaiser Plant and Bluff sites probably are attributable to emissions from the Kaiser Plant, while the hourly concentrations measured at the ASARCO Meeker site probably are attributable to emissions from the St. Regis Mill.

We used SHORTZ with the 1981 average emissions parameters given in Section 2 for the Kaiser and St. Regis plants to calculate hourly and 24-hour average SO_2 concentrations at the Kaiser Plant and Bluff sites and the ASARCO Meeker site. To evaluate the representativeness of the Benny's and Fire Station No. 12 winds, we used both sets of wind observations in the SHORTZ calculations for 10 December. Because the hourly wind speeds at Fire Station No. 12 generally exceeded the corresponding wind speeds at Benny's on 10 December, we assumed the wind speed to be independent of height in both sets of SHORTZ calculations. From the Portage Bay 0700 PST sounding provided by PSAPCA (Anderson, 1982), we estimated the top of the surface mixing layer to be about 500 meters above mean sea level with a vertical potential temperature gradient within the mixing layer of about 0.003 degrees Kelvin per meter. These values were assumed to exist throughout the day because of the moderate-to-strong wind speeds. Following the Turner (1964) definitions of the Pasquill stability categories, the neutral D category existed at McChord Air Force Base during all hours except 0300 and 0400 PST when E and F stability existed. We used the SHORTZ default rural turbulent intensities for these stability categories except that F stability was redefined as E stability for the reasons given by Cramer, *et al*. (1976).

The SO_2 concentrations observed at the Kaiser Bluff and Plant sites and the ASARCO Meeker site on 10 December 1981 are compared with the hourly SO_2 concentrations calculated by SHORTZ using Benny's and Fire Station No. 12 winds in Tables 3-17 and 3-18, respectively. As expected, both tables show a poor hour-to-hour correspondence between observed and calculated concentrations. If the Benny's winds are used in the model calculations, the relatively low 24-hour average concentration measured at the Kaiser Bluff site is overprecited by a factor of 6.83, while the

TABLE 3-17

COMPARISON OF THE OBSERVED HOURLY SO$_2$ CONCENTRATIONS ON 10 DECEMBER 1981 WITH THE CONCENTRATIONS CALCULATED USING ASARCO BENNY'S (N26TH & PEARL) WINDS

Hour (PST)	Observed Concentration (ppm)			Calculated Concentration (ppm)			Ratio of Calculated and Observed Concentrations		
	Kaiser Bluff	Kaiser Plant	ASARCO Meeker	Kaiser Bluff	Kaiser Plant	ASARCO Meeker	Kaiser Bluff	Kaiser Plant	ASARCO Meeker
0100	0.02	0.04	0.00	0.06	0.00	0.00	3.00	0.00	--
0200	0.00	0.11	0.01	0.00	0.00	0.00	--	0.00	0.00
0300	0.00	0.02	0.00	0.00	0.00	0.00	--	0.00	--
0400	0.00	0.15	0.00	0.00	0.00	0.00	--	0.00	--
0500	0.00	0.10	0.01	0.03	0.00	0.00	∞	0.00	0.00
0600	MSG	0.10	0.00	0.00	0.00	0.00	MSG	0.00	--
0700	MSG	0.01	0.01	0.00	0.00	0.00	MSG	0.00	0.00
0800	0.00	0.15	0.01	0.00	0.00	0.00	--	0.00	0.00
0900	0.00	MSG	0.00	0.03	0.00	0.00	∞	MSG	--
1000	0.00	MSG	0.01	0.13	0.00	0.00	∞	MSG	0.00
1100	0.01	0.07	0.01	0.01	0.00	0.00	1.00	0.00	0.00
1200	0.00	0.15	0.00	0.00	0.00	0.00	--	0.00	--
1300	0.00	0.11	0.01	0.02	0.00	0.00	∞	0.00	0.00
1400	0.01	0.06	0.00	0.03	0.00	0.00	3.00	0.00	--
1500	0.02	0.04	0.00	0.10	0.00	0.00	5.00	0.00	--
1600	0.00	0.11	0.00	0.12	0.00	0.00	∞	0.00	--
1700	0.00	0.08	0.01	0.08	0.00	0.00	∞	0.00	0.00
1800	0.01	0.07	0.00	0.01	0.00	0.00	1.00	0.00	--
1900	0.01	0.07	0.00	0.06	0.00	0.00	6.00	0.00	--
2000	0.01	0.07	0.00	0.13	0.00	0.00	13.00	0.00	--
2100	0.01	0.05	0.00	0.04	0.00	0.00	4.00	0.00	--
2200	0.00	0.05	0.00	0.01	0.00	0.00	∞	0.00	--
2300	0.01	0.04	0.00	0.08	0.00	0.01	8.00	0.00	∞
2400	0.01	0.04	0.02	0.03	0.00	0.00	3.00	0.00	0.00
Average	0.006	0.077	0.003	0.041	0.000	0.000	6.83	0.00	0.00

TABLE 3-18

COMPARISON OF THE OBSERVED HOURLY SO_2 CONCENTRATIONS ON 10 DECEMBER 1981 WITH THE CONCENTRATIONS CALCULATED USING PSAPCA FIRE STATION NO. 12 WINDS

Hour (PST)	Observed Concentration (ppm)			Calculated Concentration (ppm)			Ratio of Calculated and Observed Concentrations		
	Kaiser Bluff	Kaiser Plant	ASARCO Meeker	Kaiser Bluff	Kaiser Plant	ASARCO Meeker	Kaiser Bluff	Kaiser Plant	ASARCO Meeker
0100	0.02	0.04	0.00	0.01	0.00	0.00	0.50	0.00	--
0200	0.00	0.11	0.01	0.02	0.01	0.00	∞	0.09	0.00
0300	0.00	0.02	0.00	0.00	0.00	0.00	--	0.00	--
0400	0.00	0.15	0.00	0.10	0.09	0.02	∞	0.60	∞
0500	0.00	0.10	0.01	0.04	0.01	0.02	∞	0.10	2.00
0600	MSG	0.10	0.00	0.01	0.01	0.00	MSG	0.10	--
0700	MSG	0.01	0.01	0.01	0.01	0.00	MSG	1.00	0.00
0800	0.00	0.15	0.01	0.01	0.26	0.01	∞	1.73	1.00
0900	0.00	MSG	0.00	0.03	0.07	0.01	∞	MSG	∞
1000	0.00	MSG	0.01	0.06	0.00	0.01	∞	MSG	1.00
1100	0.01	0.07	0.01	0.06	0.00	0.00	6.00	0.00	0.00
1200	0.00	0.15	0.00	0.06	0.20	0.02	∞	1.33	∞
1300	0.00	0.11	0.01	0.06	0.01	0.01	∞	0.09	1.00
1400	0.01	0.06	0.00	0.02	0.00	0.00	2.00	0.00	--
1500	0.02	0.04	0.00	0.08	0.00	0.00	4.00	0.00	--
1600	0.00	0.11	0.00	0.00	0.00	0.00	--	0.00	--
1700	0.00	0.08	0.01	0.01	0.00	0.00	∞	0.00	0.00
1800	0.01	0.07	0.00	0.01	0.00	0.00	1.00	0.00	--
1900	0.01	0.07	0.00	0.13	0.00	0.00	13.00	0.00	--
2000	0.01	0.07	0.00	0.09	0.00	0.00	9.00	0.00	--
2100	0.01	0.05	0.00	0.00	0.00	0.00	0.00	0.00	--
2200	0.00	0.05	0.00	0.11	0.00	0.00	∞	0.00	--
2300	0.01	0.04	0.00	0.14	0.00	0.00	14.00	0.00	--
2400	0.01	0.04	0.02	0.04	0.00	0.00	4.00	0.00	0.00
Average	0.006	0.077	0.003	0.048	0.028	0.005	8.00	0.36	1.67

24-hour average concentrations predicted at the Kaiser Plant site and the ASARCO Meeker site are zero. If the Fire Station No. 12 winds are used in the model calculations, the relatively high 24-hour average concentration measured at the Kaiser Plant site is underpredicted by a factor of 2.78, while the relatively low 24-hour average concentrations measured at the Kaiser Bluff site and the ASARCO Meeker site are overpredicted by factors of 8.00 and 1.67, respectively. Thus, neither set of wind inputs yields a good correspondence between calculated and observed 24-hour average concentrations on 10 December 1982.

Table 3-19 compares the maximum observed and calculated 1-hour and 3-hour average SO_2 concentrations paired in space only on 10 December 1982. The calculated concentrations given in Table 3-19 for the Kaiser Bluff and Plant sites are entirely determined by Kaiser emissions, while the calculated concentrations given in the table for the ASARCO Meeker site are entirely determined by St. Regis emissions. For both sets of SHORTZ wind inputs, the calculated maximum 1-hour and 3-hour average concentrations are within a factor of 2 of the observed concentrations at the ASARCO Meeker site and are significantly higher than the observed concentrations at the Kaiser Bluff site. If the Benny's winds are used in the model calculations, no impact is predicted at the Kaiser Plant site. However, if the Fire Station No. 12 winds are used in the model calculations, the maximum 1-hour and 3-hour average concentrations calculated at the Kaiser Plant site are within a factor of 2 of the maximum observed concentrations.

We conclude from the results of the SHORTZ calculations for 10 December 1981 that, during periods of moderate-to-strong south or south-southwest winds at the ASARCO Benny's (N26th & Pearl) and the PSAPCA Fire Station No. 12 sites, the wind directions at the two sites are not very good indicators of the initial transport wind directions for the low-level emissions from the Kaiser plant. With both sets of wind inputs, the relatively low 1-hour, 3-hour and 24-hour average SO_2 concentrations measured at the Kaiser Bluff site are overpredicted, the same result as

TABLE 3-19

COMPARISON OF MAXIMUM OBSERVED AND CALCULATED 1-HOUR AND 3-HOUR AVERAGE SO_2 CONCENTRATIONS UNPAIRED IN TIME ON 10 DECEMBER 1981

Site	Observed Concentration (ppm)	Calculated Concentration (ppm)		Ratio of Calculated and Observed Concentrations	
		Benny's Winds	Fire Station No. 12 Winds	Benny's Winds	Fire Station No. 12 Winds
(a) 1-Hour Average Concentrations					
Kaiser Bluff	0.02	0.13	0.14	6.50	7.00
Kaiser Plant	0.15	0.00	0.26	0.00	1.73
ASARCO Meeker	0.02	0.01	0.02	0.50	1.00
(b) 3-Hour Average Concentrations					
Kaiser Bluff	0.01	0.10	0.10	10.00	10.00
Kaiser Plant	0.11	0.00	0.11	0.00	1.00
ASARCO Meeker	<0.01	<0.01	0.01	~ 1.00	>1.00

obtained above for the 30 March 1981 case using Benny's winds. The best correspondence between the maximum observed and calculated 1-hour and 3-hour average concentraitons unpaired in time at the Kaiser Plant site is obtained using the Fire Station No. 12 winds. However, both sets of wind inputs yield equivalent results at the Kaiser Bluff site and the ASARCO Meeker site if maximum observed and calculated 1-hour and 3-hour average concentrations unpaired in time are compared. One of the possible explanations for the results summarized in Tables 3-17 through 3-19 is that the low-level winds in the vicinity of the Kaiser plant are channeled by the terrain toward the northwest during periods of moderate-to-strong south-southwest winds at Benny's and Fire Station No. 12. It is also important to recognize that the Kaiser Plant site monitor is on Kaiser property only about 200 meters north of the dry scrubber stacks for the existing Line 4. As discussed in Section 2, these stack emissions present a challenging modeling problem due to the uncertainties about the appropriate enhancement in buoyant plume rise for 72 stacks in close proximity and the uncertainties about the effects of aerodynamic building wakes on plume rise and initial dispersion. Thus, another possible explanation for the tendency to underpredict concentrations at the Kaiser Plant site is that the current modeling approach for the Kaiser Plant overestimates the buoyant rise of the dry scrubber stack emissions, at least during periods of moderate-to-strong winds.

The 12 through 17 January 1981 Air Stagnation Episode

To assist in the discussion of this and the three other air stagnation episodes during 1981, Figure 3-15 shows the locations of the PSAPCA and ASARCO wind and SO_2 air quality monitoring sites in the Tacoma area. (Figure 3-15 was provided to the H. E. Cramer Company by PSAPCA.) The three-letter abbreviations used to define the locations of the various sites are identified by site operator and name in Table 3-20. Although the PSAPCA hourly wind

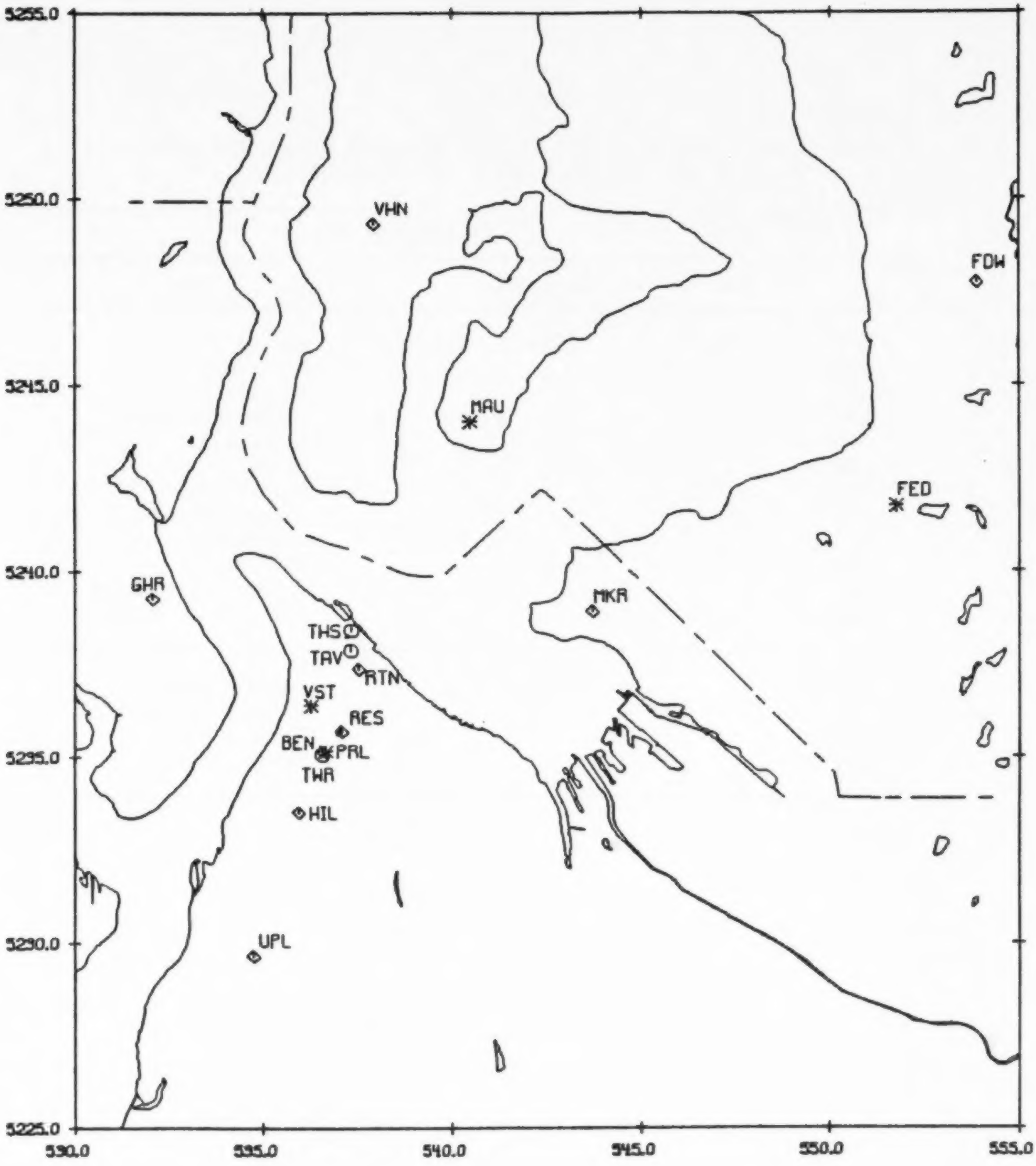

Figure 3-15. Locations of the PSAPCA and ASARCO wind and SO_2 air quality monitoring sites. (Only winds are measured at the ASARCO sites indicated by the ⦶ symbol.) The Universal Transverse Mercator (UTM) X and Y coordinates in kilometers are shown respectively at the bottom and the left-hand side of the figure.

TABLE 3-20

ABBREVIATIONS USED IN FIGURE 3-15 TO IDENTIFY PSAPCA AND ASARCO WIND AND SO_2 AIR QUALITY MONITORING SITES

Abbreviation	Monitoring Site	
	Operator	Name
RTN	ASARCO	Ruston
RES		Reservoir
BEN		Benny's
UPL		University Place
HIL		Highlands
MKR		Meeker
FDW		Federal Way
VHN		Vashon Island
GHR		Gig Harbor
THS		Tank House
TAV		Tavern (Wind Only)
TWR		Tower (Wind Only)
PRL	PSAPCA	N26th & Pearl
VST		N37th & Vassault
FED		Federal Way
MAU		Maury Island

and SO_2 concentration measurements for all of 1981 were provided to the H. E. Cramer company on computer tape, no ASARCO air quality data were available to us on tape. For each day of each air stagnation episode, we extracted from the hard copy listings submitted by ASARCO to PSAPCA the ASARCO 30-minute average wind and SO_2 concentration measurements. We then converted the ASARCO 30-minute average parameters to hourly averages for consistency with the PSAPCA data.

The 12 through 17 January 1981 air stagnation episode was characterized by shallow mixing depths and light winds. The 0700 PST sounding taken at Portage Bay on 12 January showed a surface-based inversion approximately 800 meters in depth. Similar inversions were measured at 0700 on the mornings of 13, 14 and 15 January, with the inversion depths ranging from about 600 to 650 meters. The surface-based inversion on the morning of 16 January was only about 200 meters deep, but was very strong (a vertical potential temperature gradient of about 0.055 degrees Kelvin per meter). A 200-meter surface-based inversion was also measured at 0700 PST on 17 January, but the strength of this inversion was only about half that of 16 January. If the maximum afternoon temperature at the Kaiser plant is used with the Holzworth (1972) technique to estimate the maximum afternoon (convective) mixing depth, the maximum depth never exceeded 200 meters during the 6-day period. The mechanical components of the mixing depth calculated using the techniques of Benkley and Schulman (1979) suggest that the mixing depths probably were in the range of 100 to 200 meters.

The wind speeds throughout the 12 through 17 January 1981 air stagnation episode were so light that the PSAPCA vector mean wind directions usually were reported as variable. The ASARCO wind directions on the Tacoma peninsula (the Tower, Benny's and Reservoir sites) were highly variable and almost random throughout the 6-day period. However, except for several hours of winds from the south clockwise through north, the ASARCO Meeker winds were from the northeast through southeast.

The ASARCO smelter reported zero SO_2 emissions from its Main Stack on 11 January 1981, the day preceding the air stagnation episode. The 15-minute average Main Stack SO_2 emission rates reported by ASARCO were zero during the 6-day episode with the following exceptions:

- Emissions of 781 to 3,326 grams per second during the period 1000 through 1500 PST on 12 January
- Emissions of 126 to 1,159 grams per second during the period 1000 through 2400 PST on 13 January
- Emissions of 101 to 1,109 grams per second during the first 12 hours of 14 January and less than or equal to 25 grams per second during the last 12 hours
- Emissions less than or equal to 25 grams per second throughout 15 January
- Emissions less than or equal to 50 grams per second prior to 1430 PST on 16 January, followed by emissions of 580 to 2,495 grams per second throughout the remainder of the day
- Emissions of 1,613 to 5,216 grams per second throughout 17 January

According to information provided by EPA Region 10 (Wilson, 1982b), Pennwalt burned natural gas during this air stagnation episode and Kaiser emissions were about 91 percent of the 1981 annual average emissions.

Table 3-21 summarizes the 24-hour average SO_2 concentrations measured during the 12 through 17 January 1981 air stagnation episode. During the first five days when ASARCO emissions were significantly curtailed, the maximum observed concentrations were measured at the Kaiser Bluff or ASARCO Meeker sites. Although the winds were too light to define unambiguous source-receptor relationships, the combination of: (1) minimal ASARCO emissions, and (2) the close proximity of the tideflats sources to the Meeker and Bluff sites suggests that the observed concentrations at these sites are primarily attributable to emissions from the tideflats sources. After the ASARCO smelter resumed continuous operation on 17 January, the highest observed 24-hour average concentration shifted to the ASARCO Ruston monitor; this concentration probably reflects the effects of low-level fugitive emissions from the smelter.

We selected 16 January 1981 to test SHORTZ because the SO_2 concentrations measured at the Kaiser Bluff and ASARCO Meeker sites were probably caused by emissions from the tideflats sources and because two of the 13 hourly SO_2 concentrations greater than or equal to 0.15 ppm at the Kaiser Bluff site occurred on this day. We assumed zero SO_2 emissions from Pennwalt because of the use of natural gas and zero SO_2 emissions from ASARCO, although we recognize that the ASARCO emissions during the afternoon of 16 January may have affected the observed concentrations. Based on the monthly average emission rates provided by PSAPCA (Anderson, 1982), we increased the annual average SO_2 emissions from U. S. Oil & Refining by 28 percent. We used both ASARCO Benny's (N26th & Pearl) and Meeker wind directions and wind speeds in the SHORTZ calculations. If the hourly average Benny's wind speed was less than 1 meter per second, we set the wind speed equal to 1 meter per second. Because the Meeker wind speeds were consistently higher than the Benny's wind speeds, we assumed the wind speed to be independent of height below the elevation of the Benny's wind sensor in both sets of SHORTZ calculations. The vertical potential temperature gradient for all hours was set equal to 0.040 degrees Kelvin per meter, the average of the 0700 PST Portage Bay potential temperature gradients on 16 and 17 January.

TABLE 3-21

24-HOUR AVERAGE SO_2 CONCENTRATIONS DURING THE AIR STAGNATION EPISODE OF 12 THROUGH 17 JANUARY 1981

Monitoring Site	SO_2 Concentration (ppm)					
	12 Jan	13 Jan	14 Jan	15 Jan	16 Jan	17 Jan
ASARCO						
Ruston	0.017	0.018	0.010	0.017	0.014	0.037
Reservoir	0.015	0.019	0.007	0.011	0.011	0.019
Benny's	0.006	0.017	0.012	0.014	0.010	0.015
University Place	0.007	MSG	MSG	MSG	MSG	MSG
Highlands	0.012	0.014	0.012	0.016	0.017	0.021
Meeker	MSG	0.015	0.038	0.047	0.060	0.011
Federal Way	MSG	MSG	MSG	MSG	0.021	0.005
Vashon Island	0.020	0.009	MSG	MSG	0.004	0.004
Gig Harbor	0.018	0.020	0.019	0.018	0.017	0.018
PSAPCA						
N26th & Pearl	0.004	MSG	MSG	MSG	0.008	0.015
N37th & Vassault	0.002	0.004	0.003	0.008	0.011	0.025
Federal Way	MSG	MSG	MSG	MSG	MSG	MSG
Maury Island	0.030	0.014	0.007	0.014	0.010	0.004
Kaiser						
Bluff	0.048	0.040	0.021	0.069	0.064	0.031
Plant	MSG	MSG	MSG	MSG	MSG	MSG

The mechanical component of the mixing depth was assumed to be 185 meters based on the 24-hour average wind speed at the Meeker site and the Benkley and Schulman (1979) relationship (see Equation 3-1). Following the Turner (1964) approach, the Pasquill D stability category existed at McChord Air Force Base during 17 hours of 16 January, the stable E category existed during 4 hours, the slightly unstable C category existed during 2 hours and there was a single hour with the unstable B category.

The observed hourly and 24-hour average SO_2 concentrations at the Kaiser Bluff and ASARCO Meeker sites on 16 January 1981 are compared with the concentrations calculated by SHORTZ using Benny's and Meeker winds in Tables 3-22 and 3-23, respectively. If the Benny's winds are used in the model calculations, SHORTZ closely matches the observed 24-hour average concentration at the Bluff site, but predicts no impact at the Meeker site. If the Meeker winds are used in the model calculations, SHORTZ underestimates the observed 24-hour average concentrations at both sites by a factor of about 5. As expected, the hour-to-hour correspondence between observed and calculated concentrations is poor. However, for both sets of wind inputs, Table 2-34 shows that the observed and calculated maximum 1-hour and 3-hour average concentrations paired in space only at the Bluff site are within the approximate factor of 2 accuracy generally attributed to the results of short-term dispersion model calculations in the absence of complicating factors (AMS, 1978).

We conclude from the results presented in Tables 3-22 through 3-24 that emissions from the tideflats sources probably follow curvilinear trajectories under stable, light wind conditions. The results of the SHORTZ calculations suggest that the ASARCO Benny's (N26th & Pearl) winds provide the best representation of the transport of emissions from the tideflats sources to the Kaiser Bluff site under stable, light wind conditions. These emissions then appear to be diverted toward the northwest by the elevated terrain, resulting in relatively high concentrations at the Meeker site. Because SHORTZ cannot account for this change in trajectory, SHORTZ cannot account for the observed concentrations at the Meeker site.

TABLE 3-22

COMPARISON OF THE OBSERVED HOURLY SO_2 CONCENTRATIONS ON 16 JANUARY 1981 WITH THE CONCENTRATIONS CALCULATED USING ASARCO BENNY'S (N26TH & PEARL) WINDS

Hour (PST)	Observed Concentration (ppm)		Calculated Concentration (ppm)		Ratio of Calculated and Observed Concentrations	
	Kaiser Bluff	ASARCO Meeker	Kaiser Bluff	ASARCO Meeker	Kaiser Bluff	ASARCO Meeker
0100	0.07	0.14	0.02	0.00	0.29	0.00
0200	0.09	0.16	0.24	0.00	2.67	0.00
0300	0.02	0.13	0.00	0.00	0.00	0.00
0400	0.16	0.17	0.02	0.00	0.13	0.00
0500	0.09	0.15	0.00	0.00	0.00	0.00
0600	0.15	0.12	0.00	0.00	0.00	0.00
0700	MSG	0.10	0.53	0.00	MSG	0.00
0800	MSG	0.09	0.22	0.00	MSG	0.00
0900	MSG	0.06	0.01	0.00	MSG	0.00
1000	0.05	0.06	0.07	0.00	1.40	0.00
1100	0.08	0.04	0.05	0.00	0.63	0.00
1200	0.09	0.04	0.04	0.00	0.44	0.00
1300	0.05	0.04	0.01	0.00	0.20	0.00
1400	0.07	MSG	0.00	0.00	0.00	MSG
1500	0.07	0.02	0.00	0.00	0.00	0.00
1600	0.05	0.02	0.03	0.00	0.60	0.00
1700	0.06	0.01	0.03	0.00	0.50	0.00
1800	0.04	0.02	0.00	0.00	0.00	0.00
1900	0.04	0.01	0.00	0.00	0.00	0.00
2000	0.04	0.01	0.02	0.00	0.50	0.00
2100	0.06	0.02	0.00	0.00	0.00	0.00
2200	0.04	0.02	0.00	0.00	0.00	0.00
2300	0.04	0.02	0.00	0.00	0.00	0.00
2400	0.03	0.02	0.00	0.00	0.00	0.00
Average	0.064	0.060	0.053	0.00	0.83	0.00

TABLE 3-23

COMPARISON OF THE OBSERVED HOURLY SO_2 CONCENTRATIONS ON 16 JANUARY 1981 WITH THE CONCENTRATIONS CALCULATED USING ASARCO MEEKER WINDS

Hour (PST)	Observed Concentration (ppm)		Calculated Concentration (ppm)		Ratio of Calculated and Observed Concentrations	
	Kaiser Bluff	ASARCO Meeker	Kaiser Bluff	ASARCO Meeker	Kaiser Bluff	ASARCO Meeker
0100	0.07	0.14	0.00	0.04	0.00	0.29
0200	0.09	0.16	0.00	0.04	0.00	0.25
0300	0.02	0.13	0.00	0.03	0.00	0.23
0400	0.16	0.17	0.00	0.04	0.00	0.24
0500	0.09	0.15	0.00	0.00	0.00	0.00
0600	0.15	0.12	0.00	0.03	0.00	0.25
0700	MSG	0.10	0.00	0.04	MSG	0.40
0800	MSG	0.09	0.00	0.00	MSG	0.00
0900	MSG	0.06	0.00	0.00	MSG	0.00
1000	0.05	0.06	0.00	0.00	0.00	0.00
1100	0.08	0.04	0.02	0.01	0.25	0.25
1200	0.09	0.04	0.05	0.02	0.56	0.50
1300	0.05	0.04	0.00	0.00	0.00	0.00
1400	0.07	MSG	0.21	0.00	3.00	MSG
1500	0.07	0.02	0.00	0.00	0.00	0.00
1600	0.05	0.02	0.05	0.00	1.00	0.00
1700	0.06	0.01	0.00	0.04	0.00	4.00
1800	0.04	0.02	0.00	0.04	0.00	2.00
1900	0.04	0.01	0.00	0.00	0.00	0.00
2000	0.04	0.01	0.00	0.00	0.00	0.00
2100	0.06	0.02	0.00	0.00	0.00	0.00
2200	0.04	0.02	0.00	0.00	0.00	0.00
2300	0.04	0.02	0.00	0.00	0.00	0.00
2400	0.03	0.02	0.00	0.00	0.00	0.00
Average	0.064	0.060	0.014	0.014	0.22	0.23

TABLE 3-24

COMPARISON OF MAXIMUM OBSERVED AND CALCULATED 1-HOUR AND 3-HOUR AVERAGE SO_2 CONCENTRATIONS UNPAIRED IN TIME ON 16 JANUARY 1981

Site	Observed Concentration (ppm)	Calculated Concentration (ppm)		Ratio of Calculated and Observed Concentrations	
		Benny's Winds	Meeker Winds	Benny's Winds	Meeker Winds
(a) 1-Hour Average Concentrations					
Kaiser Bluff	0.16	0.53 (0.24)*	0.21	3.31 (1.50)*	1.31
ASARCO Meeker	0.17	0.00	0.04	0.00	0.24
(b) 3-Hour Average Concentrations					
Kaiser Bluff	0.13	0.25 (0.09)*	0.09	1.92 (0.69)*	0.69
ASARCO Meeker	0.15	0.00	0.04	0.00	0.27

* The numbers enclosed by parentheses consider only the 21 hours with concentration measurements at the Kaiser Bluff site.

The 14 through 20 October 1981 Air Stagnation Episode

The 14 through 20 October 1981 air stagnation episode was characterized by light winds and shallow to relatively deep surface mixing layers. The 0600 PST upper-air soundings taken at Portage Bay on 14 and 15 October both show mixing depths of about 150 meters with an adiabatic or moist-adiabatic vertical potential temperature gradient within the surface mixing layer. The 0600 PST Portage Bay soundings for 16 and 17 October show early morning mixing depths of 300 to 400 meters with an adiabatic lapse rate within the surface mixing layer. No Portage Bay sounding was made on the morning of 18 October. The 0600 PST Portage Bay soundings on the mornings of 19 and 20 October indicate early morning mixing depths between 600 and 1,000 meters with a moist-adiabatic vertical potential temperature gradient.

The ASARCO reports of stack SO_2 emissions, which were provided by PSAPCA (Anderson, 1982), indicate that there were no SO_2 emissions from the ASARCO Main Stack during most of the period 14 through 20 October 1981. The exceptions are:

- Emissions of 655 to 8,215 grams per second during the period 0315 through 0715 PST on 14 October

- Emissions of 277 to 1,336 grams per second on 15 October

- Emissions of 252 to 832 grams per second prior to 1330 PST on 16 October

However, according to PSAPCA (Carson, 1982), ASARCO was in operation on 20 October 1981 in spite of the fact that the in-stack SO_2 monitor showed zero emissions. Although PSAPCA believes that ASARCO curtailment reports can be used to estimate emissions during periods when ASARCO is in operation and the in-stack monitor shows zero emissions, time constraints for the completion of this study precluded the use of emissions estimated from the curtailment reports.

The winds were so light during the period 14 through 20 October 1981 that the majority of the PSAPCA vector mean wind directions were recorded as variable. The scalar mean wind speeds at the ASARCO Benny's (N26th & Pearl) site were so light that the scalar wind directions may also be unreliable. For the hours during the period 14 through 20 October with Benny's wind speeds above 1 meter per second, the wind directions were from the northwest through east, while the ASARCO Meeker wind directions tended to be from the north through east-southeast. These winds suggest that: (1) The curtailed ASARCO stack and fugitive emissions may have affected SO_2 air quality on the Tacoma peninsula as well as at the Kaiser Bluff and Plant sites; and, (2) Emissions from some of the tideflats sources such as the St. Regis mill may have briefly affected SO_2 air quality at the Kaiser Bluff and Plant sites, but not at the ASARCO Meeker site.

Table 3-25 lists the observed 24-hour average SO_2 concentrations for each day during the period 14 through 20 October 1981. As expected on the basis of the ASARCO Benny's (N26th & Pearl) winds, negligible concentrations were measured at the monitoring sites north of ASARCO and the tideflats sources (Meeker, Vashon Island and Maury Island). After the reported complete curtailment of ASARCO emissions on 17 October, the 24-hour average concentrations at all sites tended to decrease. This result is probably explained by a combination of the near-zero ASARCO emissions and the absence of wind directions required for the direct transport of emissions from the tideflats sources to the air quality monitoring sites.

The 23 through 25 October 1981 Air Stagnation Episode

The 0600 PST upper-air soundings taken at Portage Bay on 23 and 24 October 1981 show mixing depths of about 150 meters with a slightly stable lapse rate within the surface mixing layer. (No sounding was made on 25 October.) Based on the maximum afternoon ambient air temperatures at the Kaiser Plant and the light wind speeds, relatively shallow mixing depths should have persisted throughout both days. According to PSAPCA (Anderson, 1982), ASARCO reported zero stack emissions beginning at 1315 PST on 16 October and continuing through 25 October. The wind speeds were so light that the PSAPCA vector mean hourly wind directions generally were recorded

TABLE 3-25

24-HOUR AVERAGE SO_2 CONCENTRATIONS DURING THE AIR STAGNATION EPISODE OF 14 THROUGH 20 OCTOBER 1980

Monitoring Site	SO_2 Concentration (ppm)						
	14 Oct	15 Oct	16 Oct	17 Oct	18 Oct	19 Oct	20 Oct
ASARCO							
Ruston	0.014	0.010	MSG	MSG	MSG	MSG	MSG
Reservoir	0.013	MSG	MSG	MSG	MSG	MSG	0.004
Benny's	MSG	MSG	MSG	0.001	0.006	0.003	0.005
University Place	MSG	MSG	MSG	MSG	MSG	MSG	0.009
Highlands	MSG	MSG	MSG	0.004	0.010	0.004	0.006
Meeker	0.011	MSG	0.000	0.000	0.000	0.000	MSG
Federal Way	0.009	0.018	0.016	0.004	0.003	0.007	MSG
Vashon Island	0.002	0.003	0.001	MSG	0.000	0.000	0.000
Gig Harbor	MSG	MSG	MSG	0.001	0.000	0.000	0.001
PSAPCA							
N26th & Pearl	0.013	0.007	0.018	0.002	0.008	0.005	0.004
N37th & Vassault	0.011	0.014	0.012	0.010	0.008	0.003	0.017
Federal Way	0.004	0.003	0.003	0.001	0.005	0.002	0.006
Maury Island	0.007	0.004	0.001	0.000	0.000	0.000	0.002
Kaiser							
Bluff	0.017	0.016	0.011	0.008	0.008	0.006	0.006
Plant	0.020	0.017	0.017	0.008	0.008	0.008	0.012

as variable. During the hours on 23 October with scalar mean wind speeds above 1 meter per second, the ASARCO Benny's (N26th & Pearl) winds tended to be from the northwest through northeast, while the ASARCO Meeker winds tended to be from the northwest through the southeast. In general, the Benny's winds were from the west through the northwest on 24 October and the Meeker winds were highly variable. A general southerly flow was indicated by the Benny's and Meeker winds on 25 October.

Table 3-26 lists the 24-hour average SO_2 concentrations measured during the period 23 through 25 October 1981. Although no stack SO_2 emissions were reported for the ASARCO smelter, the smelter was in operation (Carson, 1982), and the highest hourly SO_2 concentrations on 23 October at the Ruston, Reservoir, Benny's (N26th & Pearl), University Place and Highlands sites occurred during hours when the Benny's wind directions suggest that ASARCO was the most probable source of the SO_2. On the other hand, the highest hourly concentrations at these sites on 24 October occurred during hours with light westerly winds at Benny's. Because of the circumstantial evidence that ASARCO emissions directly affected the observed concentrations on 23 October 1981, it would be of considerable interest to determine what stack and fugitive emissions can occur when the in-stack SO_2 monitor indicates zero emissions.

One of the meteorological regimes identified in our previous study of the Tacoma area (Cramer, et al., 1976) as being conducive to the occurrence of relatively high short-term SO_2 concentrations was termed "air stagnation fumigation." When a stack plume is contained in an elevated stable layer above the top of the surface mixing layer, the plume remains aloft and does not mix to the ground until the top of the surface mixing layer reaches the height of the plume. At this time, the plume is rapidly mixed to the surface in a process called fumigation, resulting in relatively high ground-level concentrations that rarely persist for longer than 1 or 2 hours. Prior to fumigation, the angular width of the plume may be very narrow or very large, depending on the variability of the winds at plume height. We previously concluded from the simultaneous occurrence at many

TABLE 3-26

24-HOUR AVERAGE SO_2 CONCENTRATIONS DURING THE AIR STAGNATION EPISODE OF 23 THROUGH 25 OCTOBER 1981

Monitoring Site	SO_2 Concentration (ppm)		
	23 Oct	24 Oct	25 Oct
ASARCO			
Ruston	0.027	0.030	0.004
Reservoir	0.027	0.037	0.002
Benny's	0.020	0.044	0.001
University Place	0.020	0.026	0.007
Highlands	0.022	0.055	0.004
Meeker	0.019	0.039	0.024
Federal Way	0.012	0.016	0.011
Vashon island	0.001	0.006	0.002
Gig Harbor	0.005	0.020	0.000
PSAPCA			
N26th & Pearl	0.018	0.050	0.006
N37th & Vassault	0.015	0.030	0.008
Federal Way	0.010	0.016	0.007
Maury Island	0.010	0.027	0.011
Kaiser			
Bluff	MSG	MSG	MSG
Plant	0.021	0.028	0.015

or all of the monitoring sites in the Tacoma area of relatively high short-term SO_2 concentrations that the ASARCO plume is spread over a sector as large as 360 degrees prior to fumigation. Although we found in our 1976 study cases in which the emissions appeared to have been confined within sectors smaller than 360 degrees, the air stagnation fumigation calculations described in our 1976 report were restricted to the apparent 360-degree sector cases because we did not have any objective basis for specifying smaller sectors.

The Cramer, et al. (1976) air stagnation fumigation model is implemented by LONGZ under the following assumptions:

- Plume rise is determined by the stable meteorological conditions prior to fumigation
- The wind-direction distribution in the stable layer is circular (i.e., pollutants in the stable layer are spread about the stack in a circular pattern)
- When the mixing depth reaches the plume stabilization height, the pollutants are rapidly mixed to the ground (the rate of vertical mixing is determined by the vertical turbulent intensity in the unstable surface layer)

As discussed in Section 4 of this report, the air stagnation fumigation model as used by Cramer, et al. (1976) tended to underestimate the observed 3-hour average SO_2 concentrations by an average of 30 to 40 percent, probably because the wind-direction distribution at the height of the ASARCO plume was not circular. However, the sample size was too small to confirm statistically that there was a bias toward underestimation.

During the period 1400 through 1600 PST ON 24 October 1981, relatively high SO_2 concentrations were measured throughout the Tacoma area. We therefore applied LONGZ in its fumigation mode to this period.

We included in the model calculations all of the existing sources discussed in Section 2 except the ASARCO Main Stack, which we assumed to have zero emissions based on the emission rates reported by ASARCO to PSAPCA. We multiplied the 1981 average SO_2 emission rates for the Pennwalt sources by 0.90 and the 1981 average emission rates for the U. S. Oil & Refining Sources by 1.28 to adjust to the monthly average emissions provided by PSAPCA (Anderson, 1982). The mixing depth of 150 meters and the vertical potential temperature gradient of 0.003 degrees Kelvin per meter estimated from the 0600 PST Portage Bay sounding were assumed in the fumigation calculations. The 3-hour average wind speed at Benny's of 1.2 meters per second was assumed to be representative for all elevations below the elevation of the Benny's wind sensor. Following the Turner (1964) criteria, there were 2 hours of B stability and 1 hour of C stability at McChord Air Force Base during the period 1400 through 1600 PST PST. We used the LONGZ (and SHORTZ) default vertical turbulent intensity for B stability of 0.108 and the McChord 3-hour average surface temperature of 296 degrees Kelvin in the air stagnation fumigation calculations.

Table 3-27 compares the observed and calculated 3-hour average SO_2 concentrations for the period 1400 through 1600 PST on 24 October 1981. The only monitor at which the correspondence between observed and calculated concentrations is what we would expect on the basis of our previous experience with the air stagnation fumigation model is the Kaiser Plant site (no data are available for the Kaiser Bluff site). The model underpredicts the observed concentrations on the Tacoma peninsula by an order of magnitude or more except at the Ruston monitor which is significantly impacted by the assumed ASARCO fugitive emissions. Comparison of Tables 3-26 and 3-27 shows that the calculated 3-hour average concentrations are also below the observed 24-hour average concentrations at all sites except the Kaiser Plant site. We are therefore unable to reconcile the observed SO_2 concentrations on 24 October 1981 with the reported SO_2 emissions, and we recommend that the actual emissions during the episode be further investigated. The good model performance within the tideflats and the very poor model performance on the Tacoma peninsula provide circum-

TABLE 3-27

COMPARISON OF OBSERVED AND CALCULATED 3-HOUR AVERAGE SO_2 CONCENTRATIONS FOR THE PERIOD 1400 THROUGH 1600 PST on 24 OCTOBER 1981

Monitoring Site	SO_2 concentration (ppm)		Ratio of Calculated and Observed Concentrations
	Observed	Calculated*	
ASARCO			
Ruston	0.057	0.026	0.46
Reservoir	0.103	0.011	0.11
Benny's	0.197	0.009	0.05
University Place	0.060	0.005	0.08
Highlands	0.256	0.007	0.03
Meeker	0.040	0.009	0.23
Federal Way	0.020	0.003	0.15
Vashon Island	0.010	0.004	0.40
Gig Harbor	0.080	0.006	0.08
PSAPCA			
N26th & Pearl	0.183	0.010	0.05
N37th & Vassault	0.123	0.012	0.10
Federal Way	0.010	0.005	0.50
Maury Island	0.013	0.006	0.46
Kaiser			
Bluff	MSG	0.025	MSG
Plant	0.049	0.040	0.82

* LONGZ was used in the form required to implement the Cramer, et al. (1976) air stagnation fumigation model.

stantial evidence that ASARCO's fugitive emissions may have been higher than assumed in the model calculations and/or that there may have been SO_2 emissions from the ASARCO Main Stack.

The 9 through 10 November 1981 Air Stagnation Episode

No upper-air sounding is available for the morning of 9 November 1981 because the DOE specialist who takes the soundings was unable to return to the Seattle-Tacoma airport, which was closed by fog. However, the 0700 PST Portage Bay sounding on 10 November shows a relatively strong surface-based inversion (vertical potential temperature gradient of about 0.03 degrees Kelvin per meter) with a depth of about 400 meters. The 15-minute average ASARCO Main Stack SO_2 emission rates reported to PSAPCA varied from 1,210 to 3,730 grams per second prior to 0930 PST on 9 November. No ASARCO stack SO_2 emissions were reported until 0345 PST on 10 November; the 15-minute average emission rates varied from 25 to 11,012 grams per second throughout the remainder of 10 November.

The wind speeds on 9 November 1981 were so light that the majority of the PSAPCA hourly vector mean wind directions were recorded as variable. The ASARCO Benny's (N26th & Pearl) winds were from the northeast through east until about 1100 PST on 9 November when the winds shifted to the west. Hourly SO_2 concentrations above 0.10 ppm occurred at the N26th & Pearl, Ruston and Reservoir sites during the period 1200 through 1400 PST. When the Benny's winds shifted to the southeast between 1400 and 1500 PST, the hourly concentrations at the sites on the Tacoma peninsula decreased and hourly concentrations above 0.10 ppm were measured at the Gig Harbor site. One possible explanation for these variations in SO_2 concentrations is that ASARCO fugitive and/or stack emissions were transported over the Narrows (the body of water west of the Tacoma peninsula) during the early morning hours of 9 November, were advected over the Tacoma peninsula following the shift to west winds and were advected over the Gig Harbor area following the shift to southeast winds. However, the wind speeds were so light and the wind directions so variable that this hypothesis is highly speculative. In contrast to the hourly concentrations at the Gig Harbor, N26th & Pearl, Ruston and Reservoir sites on 9 November, the hourly concentrations at the Kaiser Bluff and Plant sites and the Meeker site were all below 0.10 ppm.

The wind speeds on 10 November 1981 were also so light that the majority of the PSAPCA hourly vector mean wind directions were recorded as variable. The scalar mean wind directions at the ASARCO Benny's (N26th & Pearl) and Meeker sites were highly variable throughout the day, with concurrent wind directions differing by as much as 180 degrees. However, there was a tendency for southeast winds at the Benny's and Meeker sites during the last third of 10 November. With the exception of the Ruston site at 0100 PST, no hourly concentration above 0.10 ppm was recorded in the Tacoma area.

Table 3-28 gives the 24-hour average SO_2 concentrations measured on 9 and 10 November 1981. As discussed above, the highest 24-hour average concentrations observed on 9 November, which were measured at the N26th & Pearl, Benny's, N37th & Vassault and Gig Harbor sites, are attributable to several relatively high hourly concentrations. Emissions from the ASARCO smelter appear to be the most probable cause of the relatively high concentrations. The hourly and 24-hour average concentrations on 10 November were lower and more uniform in space and time than on 9 November, a result that is possibly explained by the highly variable wind directions.

TABLE 3-28

24-HOUR AVERAGE SO_2 CONCENTRATIONS DURING THE AIR STAGNATION EPISODE OF 9 THROUGH 10 NOVEMBER 1981

Monitoring Site	SO_2 Concentration (ppm)	
	9 Nov	10 Nov
ASARCO		
Ruston	MSG	MSG
Reservoir	0.047	0.004
Benny's	0.067	0.013
University Place	0.019	0.019
Highlands	0.040	0.009
Meeker	0.040	0.026
Federal Way	0.009	0.016
Vashon Island	0.003	0.005
Gig Harbor	0.043	0.008
PSAPCA		
N26th & Pearl	0.058	0.009
N37th & Vassault	0.055	0.012
Federal Way	0.005	0.010
Maury Island	0.023	0.013
Kaiser		
Bluff	0.031	0.017
Plant	0.037	0.028

SECTION 4

STATISTICAL EVALUATION OF PREVIOUS APPLICATIONS OF THE SHORTZ/LONGZ MODELS IN THE TACOMA AREA

Time and level-of-effort constraints prevented the completion of the second subtask of this study, the evaluation of the performance of the SHORTZ/LONGZ dispersion models following procedures based on the suggestions contained in the August 1981 draft EPA report "Interim Procedures for Evaluation of Air Quality Models." The only model testing performed as part of the study described in this report consisted of the application of SHORTZ and LONGZ (air stagnation fumigation mode) to selected short-term periods when emissions from the tideflats sources appear to have affected SO_2 ambient air quality at the Kaiser Bluff and Plant sites and the ASARCO Meeker site (see Section 3.3). The purpose of these case-study calculations was to evaluate the general modeling approach under consideration for the tideflats sources, including the selection of the most representative meteorological inputs. (In the ideal situation, the model methodology developed using a case-study approach with 1981 emissions, meteorological and air quality data would then be evaluated using an independent data set such as the 1980 emissions, meteorological and air quality data.) Although it was not possible to evaluate SHORTZ or LONGZ as part of this study, it is important to note that the two models were previously tested in the Tacoma area as part of a study of the ASARCO smelter (Cramer, et al., 1976). The results of the model calculations described in detail in Appendix E of the Cramer, et al. (1976) report are used in the following paragraphs to illustrate how we had hoped to be able to evaluate model performance in this report.

The August 1981 draft EPA report "Interim Procedures for Evaluation of Air Quality Models" suggests that the evaluation of a dispersion model begin with an examination of the specific modeling problem to determine if the current Guideline on Air Quality Models (EPA, 1978) recommends a reference model for the intended type of application. If so, the reference model is

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used as a basis for comparison to determine if the proposed model is better than, comparable to, or not as good as the reference model. In the absence of a reference model, the interim procedures for model evaluation consist of two steps: (1) a technical evaluation of the proposed model, and (2) a performance evaluation of the proposed model.

When it is not possible to identify an appropriate reference model, it is suggested in the August 1981 draft EPA report that the proposed model be technically evaluated on its own merits in order to answer qualitatively the following questions:

1. Are the model formulations and internal constructs of the model well founded in theory?

2. Does the theory fit the practical aspects and constraints of the problem?

As noted in Section 1.1, EPA Region 10 considers the SHORTZ/LONGZ models to be the most appropriate dispersion models available for application to the Tacoma tideflats area, considering data base availability, source types and the topographic setting. This opinion is based on the Region's review of the technical documentation of the SHORTZ/LONGZ models (Bjorklund and Bowers, 1979) and the past performance of the models in the Region (Cramer, et al., 1976 and Bowers, et al., 1980). Consequently, we believe that the answer to each of the above questions is affirmative.

The August 1981 draft EPA report recommends that a model performance protocol be established before performing the model evaluation effort. This protocol defines in advance of the model testing the model inputs and other calculations procedures, the specific statistical measures to be used in the model evaluation and the relative importance of the various measures of performance. The Cramer, et al. (1976) study compared observed and calculated SO_2 concentrations paired in space and time, the most rigorous of the possible pairings. (Other possible comparisons of observed and calculated concentrations include concentrations paired in space only and in time only.) SHORTZ was used by Cramer, et al. (1976) to calculate hourly SO_2 concentration patterns for hours with the critical wind-speed and limited mixing conditions when the ASARCO plume was simultaneously detected by two or more air quality monitors so that the observations could be used to estimate the effective transport wind direction to the nearest degree. (The critical wind speed and limited mixing conditions are discussed in Sections 3 and 5, respectively.) LONGZ, with the modified meteorological inputs discussed in Section 4.3 of the Cramer, et al. (1976) report, was used to calculate 3-hour average concentrations for periods when air stagnation fumigation caused the occurrence of relatively high ground-level concentrations at all monitoring sites in the Tacoma area. (A discussion of air stagnation fumigation is given in Section 3.) Although the Cramer, et al. (1976) study focused attention on the highest observed and calculated concentrations, all of the observed and calculated concentrations are presented in Appendix E of their report. We used these results to calculate four measures of performance which are suggested in the August 1981 draft EPA report, but which were not used by Cramer, et al. (1976).

The first of the four measures of performance is the bias (average difference between observed and calculated concentrations) which is given by

$$\overline{\Delta\chi} = \frac{1}{N}\sum_{i=1}^{N} \Delta\chi_i \qquad (4\text{-}1)$$

$$\Delta\chi_i = \chi_{oi} - \chi_{ci} \qquad (4\text{-}2)$$

$\overline{\Delta\chi}$ = the bias or average difference between observed and calculated concentrations

N = the number of pairs of observed and calculated concentrations used to compute $\overline{\Delta\chi}$

χ_{oi} = the i^{th} observed concentration

χ_{ci} = the i^{th} calculated concentration

The second measure of performance is a measure of the noise in the results of the model calculations and is provided by the variance σ^2 of the differences

$$\sigma^2 = \frac{1}{N-1} \sum_{i=1}^{N} (\Delta\chi_i - \overline{\Delta\chi})^2 \tag{4-3}$$

The third measure of performance is a measure of the gross variability of the differences and is given by the mean square error

$$MSE = \frac{1}{N} \sum_{i=1}^{N} (\Delta\chi_i)^2 \tag{4-4}$$

The fourth measure of performance is the linear correlation coefficient between observed and calculated concentrations, defined as

$$r = \frac{\sum_{i=1}^{N} (\chi_{oi} - \bar{\chi}_o)(\chi_{ci} - \bar{\chi}_c)}{\left[\sum_{i=1}^{N} (\chi_{oi} - \bar{\chi}_o)^2 \cdot \sum_{i=1}^{N} (\chi_{ci} - \bar{\chi}_c)^2\right]^{1/2}} \tag{4-5}$$

(Equation (4-5) is continued)

$$= \frac{N \sum_{i=1}^{N} (\chi_{oi} \; \chi_{ci}) - \left(\sum_{i=1}^{N} \chi_{oi} \right) \left(\sum_{i=1}^{N} \chi_{ci} \right)}{\left[\left[N \sum_{i=1}^{N} \chi_{oi}^{2} - \left(\sum_{i=1}^{N} \chi_{oi} \right)^{2} \right] \cdot \left[N \sum_{i=1}^{N} \chi_{ci}^{2} - \left(\sum_{i=1}^{N} \chi_{ci} \right)^{2} \right] \right]^{1/2}} \qquad \begin{matrix} (4\text{-}5) \\ (\text{Cont.}) \end{matrix}$$

where $\bar{\chi}_o$ is the mean of the observed concentrations and $\bar{\chi}_c$ is the mean of the calculated concentrations. The correlation coefficient r, which ranges in absolute magnitude from 0 (no correlation between observed and calculated concentrations) to 1.0 (perfect correlation), is a measure of the degree to which the magnitude of the model predictions increases linearly with the magnitude of the observations. However, the correlation coefficient is insensitive to the rate of increase and is not a measure of absolute accuracy.

The SHORTZ performance statistics for the hours with the critical wind-speed condition and the hours with the limited mixing condition are given in Tables 4-1 and 4-2, respectively. The SHORTZ performance statistics for the two sets of hours in combination are given in Table 4-3. The performance statistics for LONGZ as an air stagnation fumigation model are given in Table 4-4. Because PSAPCA and ASARCO both have SO_2 monitors at N26th & Pearl (the separation is approximately 42 meters), separate performance statistics--based on the SO_2 concentrations measured by the two nearby monitors--are listed in Tables 4-1 through 4-4. The 95 percent confidence limits on the biases in Tables 4-1 through 4-4 were calculated using a one sample Student's t test, the 95 percent confidence limits on the variances and mean square errors were calculated using a χ^2 test and the 95 percent confidence limits on the linear correlation coefficient were calculated using the Fisher z transform (see Hoel, 1971).

TABLE 4-1

SHORTZ PERFORMANCE STATISTICS FOR THE CRITICAL WIND-SPEED CASES

Measure of Performance	95 Percent Confidence Limits*
Average Observed Concentration (ppm)	0.290 (0.413)
Number of Paired 1-Hour Concentrations	6 (7)
Bias (ppm)	$-4.67\times10^{-2} \pm 4.69\times10^{-1}$ ($-1.43\times10^{-3} \pm 4.02\times10^{-1}$)
Variance (ppm^2)	6.47×10^{-2} to 9.99×10^{-1} (6.73×10^{-2} to 7.86×10^{-1})
Mean Square Error (ppm^2)	5.48×10^{-2} to 8.46×10^{-1} (5.41×10^{-2} to 8.36×10^{-1})
Linear Correlation	-0.444 to 0.930 (-0.428 to 0.913)

* The numbers enclosed by parentheses are based on the concentrations measured by the ASARCO SO_2 monitor at N26th & Pearl rather than by the nearby PSAPCA monitor.

TABLE 4-2

SHORTZ PERFORMANCE STATISTICS FOR THE LIMITED MIXING CASES

Measure of Performance	95 Percent Confidence Limits*
Average Observed Concentration (ppm)	0.187 (0.188)
Number of Paired 1-Hour Concentrations	71 (71)
Bias (ppm)	$-1.23\text{x}10^{-2} \pm 3.04\text{x}10^{-2}$ $(-1.04\text{x}10^{-2} \pm 2.89\text{x}10^{-2})$
Variance (ppm^2)	$1.20\text{x}10^{-2}$ to $2.34\text{x}10^{-2}$ ($1.09\text{x}10^{-2}$ to $2.12\text{x}10^{-2}$)
Mean Square Error (ppm^2)	$1.16\text{x}10^{-2}$ to $2.16\text{x}10^{-2}$ ($1.05\text{x}10^{-2}$ to $1.96\text{x}10^{-2}$)
Linear Correlation	0.684 to 0.867 (0.714 to 0.881)

* The numbers enclosed by parentheses are based on the concentrations measured by the ASARCO SO_2 monitor at N26th & Pearl rather than by the nearby PSAPCA monitor.

TABLE 4-3

SHORTZ PERFORMANCE STATISTICS FOR THE CRITICAL WIND-SPEED AND LIMITED MIXING CASES

Measure of Performance	95 Percent Confidence Limits*
Average Observed Concentration (ppm)	0.196 (0.208)
Number of Paired 1-Hour Concentrations	77 (78)
Bias (ppm)	$-1.40\times10^{-2} \pm 3.68\times10^{-2}$ ($-9.62\times10^{-3} \pm 3.66\times10^{-2}$)
Variance (ppm^2)	1.89×10^{-2} to 3.52×10^{-2} (1.87×10^{-2} to 3.48×10^{-2})
Mean Square Error (ppm^2)	1.86×10^{-2} to 3.45×10^{-2} (1.85×10^{-2} to 3.45×10^{-2})
Linear Correlation	0.557 to 0.798 (0.621 to 0.830)

* The numbers enclosed by parentheses are based on the concentrations measured by the ASARCO SO_2 monitor at N26th & Pearl rather than by the nearby PSAPCA monitor.

TABLE 4-4

LONGZ PERFORMANCE STATISTICS FOR THE AIR STAGNATION FUMIGATION CASES

Measure of Performance	95 Percent Confidence Limits*
Average Observed Concentration (ppm)	0.158 (0.160)
Number of Paired 1-Hour Concentrations	10 (10)
Bias (ppm)	$4.10\text{x}10^{-2} \pm 8.51\text{x}10^{-2}$ ($4.30\text{x}10^{-2} \pm 8.64\text{x}10^{-2}$)
Variance (ppm^2)	$6.00\text{x}10^{-3}$ to $4.25\text{x}10^{-2}$ ($6.21\text{x}10^{-3}$ to $4.38\text{x}10^{-2}$)
Mean Square Error (ppm^2)	$6.22\text{x}10^{-3}$ to $4.38\text{x}10^{-2}$ ($6.47\text{x}10^{-3}$ to $4.56\text{x}10^{-2}$)
Linear Correlation	-0.746 to 0.499 (-0.718 to 0.543)

* The numbers enclosed by parentheses are based on the concentrations measured by the ASARCO SO_2 monitor at N26th & Pearl rather than by the nearby PSAPCA monitor.

In the absence of a model performance evaluation protocol, the relative importance of each of the measures of performance listed in Tables 4-1 through 4-4 is a matter of personal judgment. For example, we consider absence of bias in the results of dispersion model calculations to be of critical importance. For convenience, Table 4-5 gives the biases and 95 percent confidence limits, normalized by dividing by the corresponding averages of the observed concentrations. Inspection of Table 4-5 shows that the hypothesis that SHORTZ and LONGZ are unbiased cannot be rejected at the 95 percent confidence level. The results also illustrate the sensitivity of apparent model performance to uncertainties in air quality measurements (see the differences in the biases obtained for the critical wind-speed cases using the PSAPCA and ASARCO N26th & Pearl concentration measurements). Another model attribute of concern is the variability of the model's predictions. To illustrate the variability in the SHORTZ and LONGZ concentration calculations, Table 4-6 gives the root mean square (RMS) errors (square roots of the mean square errors), normalized by dividing by corresponding averages of the observed concentrations. The typical RMS error is about 80 percent of the observed concentration, a result that is consistent with the approximate factor of 2 accuracy generally attributed to the results of short-term dispersion model calculations (AMS, 1978).

TABLE 4-5

BIASES AND 95 PERCENT CONFIDENCE LIMITS NORMALIZED BY DIVIDING BY THE AVERAGE OBSERVED CONCENTRATIONS

Meteorological Regime	Normalized Bias and 95% Confidence Limits*
Critical Wind-Speed Condition	-0.16 ± 1.62 (0.00 ± 0.97)
Limited Mixing Condition	-0.07 ± 0.16 (-0.06 ± 0.15)
Critical Wind-Speed and Limited Mixing Conditions	-0.07 ± 0.19 (-0.05 ± 0.18)
Air Stagnation Fumigation	0.26 ± 0.54 (0.27 ± 0.54)

* The numbers enclosed by parentheses are based on the concentrations measured by the ASARCO SO_2 monitor at N26th & Pearl rather than by the nearby PSAPCA monitor.

TABLE 4-6

ROOT MEAN SQUARE (RMS) ERRORS NORMALIZED BY DIVIDING BY THE AVERAGE OBSERVED CONCENTRATIONS

Meteorological Regime	Normalized RMS Error*
Critical Wind-Speed Condition	1.29 (0.90)
Limited Mixing Condition	0.68 (0.64)
Critical Wind-Speed and Limited Mixing Conditions	0.82 (0.77)
Air Stagnation Fumigation	0.73 (0.73)

* The numbers enclosed by parentheses are based on the concentrations measured by the ASARCO SO_2 monitor at N26th & Pearl rather than by the nearby PSAPCA monitor.

SECTION 5

PRELIMINARY SHORTZ/LONGZ DISPERSION MODEL METHODOLOGY

5.1 SHORTZ DISPERSION MODEL METHODOLOGY

Source Inputs

Our preliminary SHORTZ source inputs for the existing and proposed SO_2 sources in and adjacent to the Tacoma tideflats area are given in Section 2. Because these inputs were developed from information provided by EPA Region 10 and PSAPCA, we suggest that they be reviewed by these agencies before they are used in any SHORTZ calculations for regulatory purposes. For example, the source inputs given in Section 2 for the proposed new SO_2 sources at the Kaiser Plant are based on the best information available during the course of our study and are subject to change. Section 2 of this report and Section 2.1.2 of the report by Bjorklund and Bowers (1982) provide guidance on how to develop SHORTZ source inputs for new sources in the tideflats area.

Receptor Inputs

The maximum SO_2 air quality impacts of emissions from the existing and proposed sources located in and adjacent to the Tacoma tideflats area can be expected to occur within the area shown in Figure 1-1. The Universal Transverse Mercator (UTM) X (east-west) coordinates of this area range from 537 to 552 kilometers, while the UTM Y (north-south) coordinates range from 5,230 to 5,242 kilometers. We believe that the minimum receptor spacing required to detect the maximum short-term concentrations produced by emissions from the individual and combined sources is 500 meters. Consequently, our suggested receptor array covers the area shown in Figure 1-1 with receptors placed at 500-meter invertals in a Cartesian coordinate system (UTM coordinates). These SHORTZ receptor inputs in meters, including receptor elevations in meters above mean sea level (MSL), are contained in

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Appendix B. In addition to the regular receptor array in Appendix B, EPA Region 10, PSAPCA and the Washington DOE may wish to place discrete receptors at the locations of SO_2 air quality monitors and other points of interest. Table 5-1 gives the UTM coordinates and elevations of the SO_2 air quality monitors in and adjacent to the Tacoma tideflats area.

Meteorological Inputs

Table 5-2 lists the hourly meteorological inputs required by the SHORTZ model. One of the major objectives of the study described in this report was to determine the most representative wind inputs for use in the SHORTZ calculations. Our review of the available wind and SO_2 air quality data (see Section 3) indicates that wind measurements made at a single point in or adjacent to the tideflats area cannot be expected to be representative of the winds affecting the transport and dispersion of emissions from all of the existing and proposed sources under all meteorological conditions. If wind data from a single site are selected for modeling purposes as required by the SHORTZ/LONGZ models, we believe that--of the wind data available for use in this study--the ASARCO Benny's (N26th & Pearl) winds are most likely to be representative of the winds affecting the transport and dispersion of emissions from all of the existing and proposed SO_2 sources under most meteorological conditions. We consider the ASARCO Benny's scalar mean winds to be preferable for modeling purposes to the PSAPCA N26th & Pearl vector mean winds for the reasons given in the following paragraph. It is important to note that the SHORTZ/LONGZ models assume that the wind speed below the reference level (above mean sea level) is equal to the reference level wind speed. If the reference level is defined as the height above mean sea level of the Benny's wind sensor, this model assumption is supported by the wind-speed data from the PSAPCA Fire Station No. 12, Willard School and N26th & Pearl sites (see Section 3.1).

The uncertainty in measured wind directions increases as the wind speed decreases. For example, with calm winds (zero wind speeds) the measured "wind direction" has no physical meaning and, in the absence of instrumentation problems, generally should correspond to the wind direction from the last instantaneous wind observation with a wind speed above the instrument threshold wind speed. According to PSAPCA (Carson, 1982), PSAPCA hourly wind directions are vector averages only if the scalar average wind speeds are greater than or equal to 1.5 knots (0.77 meters per second). If the hourly scalar average wind speed is less than 1.5 knots, PSAPCA records the wind direction as variable because of the uncertainties in measured wind directions under light wind conditions. ASARCO, on the other hand, computes scalar average wind speeds and wind directions for all wind speeds, including very light wind speeds. As indicated in Section 3, some of the highest concentrations measured in and adjacent to the Tacoma tideflats area occur with hourly scalar average wind speeds below 1.5 knots. Thus, the ASARCO scalar wind directions provide the only available information on wind directions during these periods. It has also been our experience that scalar average wind speeds are more reliable for modeling purposes than vector average wind speeds when the wind speed is below about 2 meters per second. For these reasons, we recommend the use of the ASARCO Benny's (N26th & Pearl) winds in preference to the PSAPCA N26th & Pearl winds.

We suggest that the majority of the SHORTZ hourly meteorological inputs other than reference level wind direction and wind speed be assigned on the basis of the Pasquill stability category defined using the Turner (1964) scheme, which relates cloud cover and surface wind speed to stability. Because of time constraints, we used McChord Air Force Base cloud-cover and wind-speed observations to develop hourly meteorological inputs for use in this study. However, we believe that it would be more appropriate to merge the McChord Air Force Base cloud-cover observations with the concurrent Benny's wind-speed observations to assign stability. The SHORTZ default values for the wind-profile exponent and for the hourly vertical (σ'_E) and lateral (σ'_A) turbulent intensities for rural areas are listed in Tables 5-3 and 5-4, respectively. We point out that our previous study of the Tacoma area indicated that hours with F stability, as defined by Turner (1964), should be redefined as E stability to account for the effects of surface

TABLE 5-1

UNIVERSAL TRANSVERSE MERCATOR (UTM) COORDINATES AND ELEVATIONS ABOVE MEAN SEA LEVEL (MSL) OF THE SO_2 AIR QUALITY MONITORS IN AND ADJACENT TO THE TACOMA TIDEFLATS AREA

Monitoring Site		Coordinates		Elevation (m MSL)
Operator	Name	UTM X (m)	UTM Y (m)	
ASARCO	Ruston	537,400	5,237,360	76
	Reservoir	537,090	5,235,670	131
	Benny's	536,650	5,235,120	122
	University Place	534,660	5,229,660	117
	Highlands	535,950	5,233,500	110
	Meeker	543,600	5,238,750	104
	Federal Way	553,970	5,247,780	130
	Vashon Island	538,100	5,249,300	104
	Gig Harbor	531,700	5,239,440	104
PSAPCA	N26th & Pearl	536,680	5,235,150	123
	N37th & Vassault	536,290	5,236,380	109
	Federal Way	551,770	5,241,750	143
	Maury Island	540,500	5,244,000	119
Kaiser	Bluff	548,400	5,235,410	125
	Plant	547,575	5,234,190	3

TABLE 5-2

HOURLY METEOROLOGICAL INPUTS REQUIRED BY THE SHORTZ PROGRAM

Parameter	Definition
$\bar{u}_R$	Mean wind speed (m/sec) at height z_R
DD	Mean wind direction (deg) at height z_R
p	Wind-profile exponent
σ'_E	Wind azimuth-angle standard deviation (rad) or lateral turbulent intensity
σ'_E	Wind elevation-angle standard deviation(rad) or vertical turbulent intensity
T_a	Ambient air temperature (°K)
H_m	Depth of surface mixing layer (m)
$\frac{\partial\theta}{\partial z}$	Vertical potential temperature gradient (°K/m)

TABLE 5-3

SHORTZ AND LONGZ DEFAULT VALUES FOR THE WIND-PROFILE EXPONENT

Pasquill Stability Category	Wind Speed (m/sec)					
	0.0 - 1.5	1.6 - 3.1	3.2 - 5.1	5.2 - 8.2	8.3 - 10.8	>10.8
A	0.10	0.10	0.10*	0.10*	0.10*	0.10*
B	0.15	0.10	0.10	0.10*	0.10*	0.10*
C	0.20	0.15	0.10	0.10	0.10	0.10
D	0.25	0.20	0.15	0.10	0.10	0.10
E	0.30*	0.25	0.20	0.15*	0.10*	0.10*
F	0.40	0.30	0.20*	0.15*	0.10*	0.10*

* These combinations of wind-speed and Pasquill stability categories cannot occur according to the Turner (1964) definitions of the Pasquill stability categories.

TABLE 5-4

DEFAULT VALUES FOR HOURLY TURBULENT INTENSITIES IN RURAL AREAS

Pasquill Stability Category	Vertical Intensity σ'_E (rad)	Lateral Intensity σ'_A (rad)
A	0.1745	0.2495
B	0.1080	0.1544
C	0.0735	0.1051
D	0.0465	0.0665
E	0.0350	0.0501
F	0.0235	0.0336

roughness elements and heat sources. Although we used McChord Air Force Base ambient air temperatures in the SHORTZ calculations described in this study, we believe that the temperatures from one of the two N26th & Pearl sites or from Fire Station No. 12 probably are more suitable. In the absence of any detailed climatology of thermal stratifications in the Tacoma area, we recommend the vertical potential temperature gradients suggested by Bjorklund and Bowers (1982) for use with SHORTZ in humid regions. These potential temperature gradients are listed in Table 5-5. Because of time constraints, we used the mixing depths estimated by Cramer, et al. (1976) and listed in Table 5-6 to develop hourly meteorological inputs for selected "worst-case" short-term periods. We believe that more appropriate mixing depths for these periods could be derived from the Portage Bay upper-air soundings and acoustic sounder measurements (see Section 3.1).

The Cramer, et al. (1976) study identified three important meteorological regimes for emissions from the ASARCO Main Stack. Two of these regimes, the critical wind-speed condition and fumigation, are discussed in Section 3. The third meteorological regime described by Cramer, et al. (1976), which was defined as "limited mixing", consists of the combination of light winds with the ASARCO plume contained within the surface mixing layer, especially with neutral or slightly stable conditions within the mixing layer. The limited mixing condition usually can be expected to cause the highest 1-hour to 3-hour average concentrations calculated by SHORTZ. Cramer, et al. (1976) found fumigation to be the least important of the three meteorological regimes. Although the study described in this report focused attention on the sources within the tideflats, we have not found any reasons to change the basic conclusions of the 1976 study. However, we point out that we neglected the effects of ASARCO fugitive emissions in our 1976 study because they were unquantified and only a small fraction of the Main Stack emissions. The air quality measurements at the ASARCO Ruston and PSAPCA N37th & Vassault sites, which were not in existence in 1976, indicate that ASARCO fugitive emissions can cause relatively high SO_2 concentrations in the immediate vicinity of the

TABLE 5-5

VERTICAL POTENTIAL TEMPERATURE GRADIENTS SUGGESTED FOR HUMID REGIONS

Pasquill Stability Category	Wind Speed (m/sec)					
	0.0 - 1.5	1.6 - 3.1	3.2 - 5.1	5.2 - 8.2	8.3 - 10.8	>10.8
A	0.000	0.000	0.000*	0.000*	0.000*	0.000*
B	0.000	0.000	0.000	0.000*	0.000*	0.000*
C	0.000	0.000	0.000	0.000	0.000	0.000
D	0.015	0.010	0.005	0.003	0.003	0.003
E	0.030*	0.020	0.015	0.010*	0.003*	0.003*
F	0.035	0.025	0.015*	0.010*	0.003*	0.003*

* These combinations of wind-speed and Pasquill stability categories cannot occur according to the Turner (1964) definitions of the Pasquill stability categories.

TABLE 5-6
MIXING DEPTHS IN METERS*

Pasquill Stability Category	Wind Speed (m/sec)					
	0.0 - 1.5	1.6 - 3.1	3.2 - 5.1	5.2 - 8.2	8.3 - 10.8	>10.8
A	875	940	---	---	---	---
B	875	940	940	---	---	---
C	875	940	940	1000	1000	1000
D	500	595	690	875	1000	1000
E	125	250	440	---	---	---

* From Table 3-9 of Cramer, _et al_. (1976).

smelter. With the possible exception of air stagnation episodes, we have not found any firm evidence that ASARCO fugitive emissions have a significant air quality impact at the distances of the other SO_2 air quality monitoring sites.

The important meteorological regimes for the ASARCO smelter are also important meteorological regimes for the existing and proposed SO_2 sources in the tideflats. To identify 24-hour critical wind-speed cases, we used our persistence search (PRSIST) data analysis program with the ASARCO Benny's (N26th & Pearl) wind data and concurrent McChord Air Force Base Pasquill stability categories (Turner, 1964 method) to isolate all periods when winds greater than or equal to 4 meters per second persisted within any 25-degree sector for 20 or more hours and the stability categories were C, D or the combined E and F categories. Nine periods satisfied these criteria. Because of the close proximity to elevated terrain of sources such as St. Regis on the west wide of the tideflats and the proposed Tacoma City Light plant on the east side of the tideflats, we examined the same data set for persistent limited mixing cases with wind directions toward elevated terrain. PRSIST identified five cases when winds less than or equal to 4 meters per second persisted within a 25-degree sector for 20 or more hours and there were no more than 5 hours with unstable (A, B, and C categories) conditions. The 25-degree sector was required to be in the range of 180 to 250 degrees or of 035 to 085 degrees, the wind directions required to transport emissions from the tideflats sources toward elevated terrain. Our criteria for the 3-hour critical wind-speed cases were: (1) wind directions within a 2-degree sector, (2) neutral D stability during all 3 hours, and (3) mean wind speeds greater than or equal to 4 meters per second. Thirteen 3-hour periods satisfied these criteria. Finally, the criteria for our 3-hour limited mixing cases were: (1) wind directions within a 3-degree sector, (2) stable (the combined E and F categories) conditions during all 3 hours, (3) wind speeds less than or equal to 2.5 meters per second, and (4) the wind directions required to transport emissions from the tideflats sources toward elevated terrain (winds in the sector 180 to 250 degrees or in the sector 035 to 085 degrees). Ten 3-hour periods satisfied these criteria. The SHORTZ hourly meteorological inputs for the "worst-case" 3-hour and 24-hour periods, developed using the procedures discussed above, are listed in Appendix C. The "worst-case" 3-hour periods also contain the "worst-case" 1-hour periods. We point out that the minimum hourly scalar average wind speed during these cases is 1.3 meters per second, which is almost double the wind speed below which PSAPCA records wind directions as variable.

Maximum 5-minute average SO_2 concentrations may be estimated from the maximum 1-hour centerline concentrations calculated by SHORTZ using the $t^{1/5}$ law of Osipov (1972) and others. Specifically, the 5-minute centerline concentration is given by

$$\chi_{c\ell}\{5\text{ min}\} = \left(\frac{60}{5}\right)^{1/5} \chi_{c\ell}\{60\text{ min}\} = 1.64\ \chi_{c\ell}\ \{60\text{ min}\} \qquad (5\text{-}1)$$

It is important to recognize that the ratios of the maximum 5-minute average to maximum hourly average SO_2 concentrations measured by PSAPCA generally exceed the 1.64 ratio given by Equation (5-1). For example, the ratio of the N26th & Pearl 5-minute average concentration ending at 1432 PST on 17 June 1980 (1.16 ppm) to the hourly average concentration ending at 1455 PST on 17 June (0.44 ppm) is 2.64. We believe that this result is explained by the fact that the location of the air quality monitor was approximately one hourly lateral dispersion coefficient σ_y off the centerline of the plume from the ASARCO Main Stack. The hourly concentration one σ_y off the plume centerline is reduced by the factor

$$\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] = \exp\left[-\frac{1}{2}\left(\frac{\sigma_y}{\sigma_y}\right)^2\right] = 0.61 \qquad (5\text{-}2)$$

Assuming that the N26th & Pearl site was on the centerline of the 5-minute average plume during 5 minutes of the 60-minute period ending at 1455 PST, the ratio of the maximum observed 5-minute and 60-minute average concentrations is

$$\frac{1.64\ \chi_{c\ell}\{60\ \text{min}\}}{0.61\ \chi_{c\ell}\{60\ \text{min}\}} = 2.69 \qquad (5\text{-}3)$$

Because our regular receptor grid with a 500-meter spacing will not necessarily detect hourly centerline concentrations for a specific source, the SHORTZ user may wish to place discrete receptors in polar coordinates along radials extending from the source in the directions of downwind transport for the hours used in the SHORTZ calculations.

Program Control Parameters

Section 3 of the report by Bjorklund and Bowers (1982) provides a detailed discussion of how to execute the SHORTZ computer program. As an example, Table 5-7 gives the SHORTZ program control parameters for a run that will calculate the 1-hour, 3-hour and 24-hour average SO_2 concentrations produced by emissions from the existing sources (Section 2) at the regular receptors (Appendix B) and discrete receptors (Table 5-1) discussed above for each of three 24-hour periods. Although parameters NHOURS and ISW(1) enable SHORTZ to use 2-hour average, 3-hour average, etc. meteorological inputs, we recommend that hourly inputs be used with SHORTZ. The parameter

TABLE 5-7

SHORTZ PROGRAM CONTROL PARAMETERS FOR AN EXAMPLE PROBLEM

SHORTZ Input Parameter	Meaning of Parameter	Optional or Recommended Value of Parameter
NSOURC	No. of Input Sources	33 (Optional)
NXPNTS	No. of Cartesian East-West Receptor Locations or Polar Radial Receptor Distances	31 (Optional)
NYPNTS	No. of Cartesian North-South Receptor Locations or Polar Azimuth Bearings	25 (Optional)
NHOURS	No. of Sets of Meteorological Inputs per Day	24 (Recommended and Default Value)
NDAYS	Number of Days or Cases	3 (Optional)
NGROUP	No. of Source Combinations in the Output	7 (Optional)
NXWYPT	No. of Discrete Receptors	15 (Optional)
ISW(1)	Averaging Time in Hours for the Meteorological Inputs	1 (Recommended and Default Value)
ISW(2)	Define as "1" if Concentrations at Base Rate ISW(1) are to be Printed	1 (Optional)
ISW(3)	No. of Hours in First Concentration Averaging Time	3 (Optional)
ISW(4)	No. of Hours in Second Concentration Averaging Time	24 (Optional)
ISW(5)	No. of Hours in Third Concentration Averaging Time	0 (Optional)
ISW(6)	Program Control and Source Data are Not Printed ("0"), only Program Control Data are Printed ("1"), Only Source Data are Printed ("2") or Both Program Control Source Data are Printed ("3")	3 (Optional)

TABLE 5-7 (Continued)

SHORTZ Input Parameter	Meaning of Parameter	Optional or Recommended Value of Parameter
ISW(7)	Define as "1" if Terrain Elevations Are Used	1 (Recommended)
ISW(8)	Define as "1" to List Meteorological Inputs	1 (Optional)
ISW(9)	Define as "1" if Wind Speed a Function of Height AGL Rather than Height MSL	0 (Recommended and Default Value)
ISW(10)	Define Print Output Unit Other than Unit "6"	0 (Default to Unit 6)
ISW(11)	Define as "1" if Concentrations are to be Averaged Over Days or Cases	0 (Optional)
ISW(12)	Used Ony When Standard Source Input Format Not Used	0 (Optional)
ISW(13)	Cartesian ("0") or Polar ("1") Coordinate Regular Receptor Array	0 (Optional)
ISW(14)	Cartesian ("0") or Polar ("1") Coordinate Discrete Receptor Array	0 (Optional)
ISW(15)	Cartesian ("0") or Polar ("1) Source Coordinates	0 (Optional)
ISW(16)	Define as "0" for Same Turbulent Intensities for All Source Types	0 (Recommended and Default Value)
ISW(17)	Rural ("0") or Urban ("1") Mode	0 (Recommended and Default Value)
TK	Units Conversion Factor	381.68 (Concentration in ppm)
ZR	Wind Speed Measurement Height above HA (m)	124.5 (Recommended)
HA	Elevation above MSL of Weather Station (m)	3 (Recommended)

TABLE 5-7 (Continued)

SHORTZ Input Parameter	Meaning of Parameter	Optional or Recommended Value of Parameter
GAMMA1	Adiabatic Plume Rise Entrainment Coefficient	0.60 (Recommended and Default Value)
GAMMA2	Stable Plume Rise Entrainment Coefficient	0.66 (Recommended and Default Value)
XRY	Distance Over Which Rectilinear Lateral Expansion Occurs (m)	50 (Recommended and Default Value)
DECAY	Exponential Decay Coefficient for Physical or Chemical Depletion (sec^{-1})	0 (Recommended and Default Value)
ROTATE	Angular Displacement of Receptor Grid from True North (deg)	0 (Recommended and Default Value)
UTMX	X Origin of Polar Coordinates (m)	0 (Optional)
UTMY	Y Origin of Polar Coordinates (m)	0 (Optional)

NGROUP in our example is set equal to "7" to enable output of the concentrations calculated for each of the six source complexes as well as the concentrations calculated for the combined sources. The value suggested for the ISW(2) parameter of "1" directs SHORTZ to print the calculated hourly average concentrations. If the user is interested only in concentrations for longer averaging times, the amount of print output can be considerably reduced by setting ISW(2) equal to the default value ("0" or not punched). The ISW(7), ISW(9), ISW(16), ISW(17) and XRY parameters should always be defined as shown in Table 5-7 for application to the tideflats area. For SO_2 emission rates in grams per second, TK equal to "381.68" converts the calculated concentrations to units of ppm. Parameter KUNR (not shown in Table 5-7) should be entered as "parts per million" to obtain the correct units label on the output tables. Table 5-7 assumes that mixing depths from Portage Bay are measured from an elevation HA that is 3 meters above mean sea level. The Benny's wind measurement height is 127.5 meters above mean sea level so that the wind-speed reference level ZR is 124.5 meters above HA. We recommend the use of the default values of the entrainment coefficients GAMMA1 and GAMMA2, which are from Briggs (1972). However, a GAMMA2 of 0.6 might be justified on the basis of the more recent Briggs (1975) paper. For the time and distance scales of concern, we doubt that depletion of SO_2 by chemical transformations and deposition is likely to be of concern and have therefore set the DECAY parameter equal to "0" (no depletion). Because we believe that the uncertainties in the Benny's wind directions are larger than the approximate 0.5-degree displacement of the UTM coordinate system from true north, we see no need to use the ROTATE parameter. The parameters UTMX and UTMY define the origin in UTM coordinates of the regular receptor array and/or of the discrete receptor array if polar coordinates are used. For example, the regular receptor array in Cartesian coordinates can be used in combination with discrete receptors in a polar coordinate system centered on a stack whose UTM X and Y coordinates are used to define parameters UTMX and UTMY.

5.2 LONGZ DISPERSION MODEL METHODOLOGY

Source Inputs

See the discussion of SHORTZ in Section 5.1.

Receptor Inputs

See the discussion of SHORTZ in Section 5.1.

Meteorological Inputs

Table 5-8 lists the seasonal and/or annual meteorological inputs required by the LONGZ model. The principal meteorological input is a STAR summary (statistical tabulation of the joint frequency of occurrence of wind-speed and wind-direction categories, classified according to the Pasquill stability categories). The best annual STAR summary currently available to the H. E. Cramer Company for the Tacoma area is the 1972 annual STAR summary developed by Cramer, et al. (1976) using PSAPCA N26th & Pearl wind data and concurrent McChord Air Force Base cloud-cover data. This STAR summary is listed in Appendix C. We suggest the use of the mixing depths contained in Table 5-6 in LONGZ calculations for the tideflats area. Based on Seattle normal daily maximum, minimum and average temperatures, Cramer, et al. assumed the average temperatures for the unstable (A, B and C), the neutral (D) and the stable (combined E and F) Pasquill stability categories to be 288, 284 and 279 degrees Kelvin, respectively. We recommend that the vertical potential temperature gradients given in Table 5-5 and the LONGZ default values for all of the remaining meteorological inputs be used in the model calculations for the tideflats area.

Program Control Parameters

Section 4 of the report by Bjorklund and Bowers (1982) provides a detailed discussion of how to execute the LONGZ computer program. As an

TABLE 5-8

TABLES OF METEOROLOGICAL INPUTS REQUIRED BY THE LONGZ PROGRAM

Parameter/Table	Definition
$f_{i,j,k,\ell}$	Frequency distribution of wind-speed and wind-direction categories by stability or time-of-day categories for the ℓ^{th} season
$\bar{u}\{z_R\}_i$	Mean wind speed (m/sec) at height z_R for the i^{th} wind-speed category
$p_{i,k}$	Wind-profile exponent for the i^{th} wind-speed category and k^{th} stability or time-of-day category
$\sigma'_{E;i,k}$	Standard deviation of the wind-elevation angle (rad) for the i^{th} wind-speed category and k^{th} stability or time-of-day category
$T_{a;k,\ell}$	Ambient air temperature (°K) for the k^{th} stability or time-of-day category and ℓ^{th} season
$\frac{\partial\theta}{\partial z}_{i,k}$	Vertical potential temperature gradient (°K/m) for the i^{th} wind-speed category and k^{th} stability or time-of-day category
$H_{m;i,k,\ell}$	Median surface mixing depth (m) for the i^{th} windspeed category, k^{th} stability or time-of-day category and ℓ^{th} season

example, Table 5-9 gives the LONGZ program control parameters for a run that will use the 1972 annual STAR deck (16 wind-direction categories, 6 wind-speed categories and 5 stability categories) to calculate the annual average concentrations produced by emissions from the existing sources (Section 2) at the regular receptors (Appendix B) and at the discrete receptors discussed in Section 5.1. Parameters ISW(8), ISW(9), ISW(16) and ISW(17) should always be used as defined in Table 5-9 in LONGZ calculations for the tideflats area. If TK is defined as "381.68" to obtain SO_2 concentrations in units of ppm for emission rates in grams per second, parameter LUNT (not shown in Table 5-9) should be entered as "parts per million" to obtain the correct units label on the output tables. The difference in ZR between Tables 5-7 and 5-9 results from the different ASARCO Benny's (N26th & Pearl) and PSAPCA N26th & Pearl wind measurement heights above mean sea level. (Table 5-9 assumes that the STAR summary is based on PSAPCA N26th & Pearl winds.) Most of the remaining LONGZ program control parameters in Table 5-9 are identical or analogous to the SHORTZ program control parameters which are discussed in Section 5.1.

5.3 ASSESSMENT OF THE PRELIMINARY SHORTZ/LONGZ DISPERSION MODEL METHODOLOGY

The SHORTZ/LONGZ dispersion model methodology suggested in Sections 5.1 and 5.2 is preliminary because it is based on an incomplete analysis of all of the existing emissions, meteorological and SO_2 air quality data and an incomplete model evaluation effort. Nevertheless, the suggested methodology is based on what is perhaps the most comprehensive analysis to date of meteorological and SO_2 air quality data from the tideflats area. We believe that the results of this study in combination with the results of our previous study of the Tacoma area (Cramer, et al., 1976) provide qualitative support for the interim use of the methodology outlined in Sections 5.1 and 5.2. However, this methodology should be used with common sense and a recognition of the uncertainties identified by the trial SHORTZ calculations described in this report. For example, the air quality impacts on the

TABLE 5-9

LONGZ PROGRAM CONTROL PARAMETERS FOR AN EXAMPLE PROBLEM

LONGZ Input Parameter	Meaning of Parameter	Optional or Recommended Value of Parameter
NSOURC	No. of Input Sources	33 (Optional)
NXPNTS	No. of Cartesian East-West Receptor Locations or Polar Radial Receptor Distances	31 (Optional)
NYPNTS	No. of Cartesian North-South Receptor Locations or Polar Azimuth Bearings	25 (Optional)
NSEASN	No. of Seasons (Annual Assumed if "1")	1 (Recommended and Default Value)
NSPEED	No. of Wind-Speed Categories	6 (Recommended and Default Value)
NSCTOR	No. of Wind-Direction Categories	16 (Recommended and Default Value)
NSTBL	No. of Pasquill Stability Categories	5 (Recommended and Default Value)
NGROUP	No. of Source Combinations in the Output	7 (Optional)
NXWYPT	No. of Discrete Receptors	15 Optional
ISW(1)	Tape Input Is Used (>"0") or Is Not Used ("0")	0 (Optional and Default Value)
ISW(2)	Tape Output Is Used (>"0") or Is Not Used ("0")	0 (Optional and Default Value)
ISW(3)	Seasonal Concentrations Are Printed ("1") or Are Not Printed ("0")	0 (Optional and Default Value)
ISW(4)	Annual Concentrations Are Printed ("1") or Are Not Printed ("0")	1 (Recommended)

TABLE 5-9 (Continued)

LONGZ Input Parameter	Meaning of Parameter	Optional or Recommended Value of Parameter
ISW(5)	Specifies Which Inputs Other Than Source Inputs Are Printed	1 (Optional)
ISW(6)	Card Source Inputs Are Not Printed ("0") or Are Printed ("1")	1 (Recommended)
ISW(7)	Tape Source Inputs Are Not Printed ("0") or Are Printed ("1")	1 (Recommended)
ISW(8)	Define as "1" if Terrain Elevations Are Used	1 (Recommended)
ISW(9)	Define as "1" if Wind Speed a Function of height AGL Rather than Height MSL	0 (Recommended and Default Value)
ISW(10)	Define Print Output Unit Other Than Unit "6"	0 (Default to Unit 6)
ISW(11)	Define as "1" if STAR Format Differs from Standard Format	0 (Optional)
ISW(12)	Used Only When Standard Source Input Format Not Used	0 (Optional)
ISW(13)	Cartesian ("0") or Polar ("1") Coordinate Regular Receptor Array	0 (Optional)
ISW(14)	Cartesian ("0") or Polar ("1") Coordinate Discrete Receptor Array	0 (Optional)
ISW(15)	Cartesian ("0") or Polar ("1) Source Coordinates	0 (Optional)
ISW(16)	Define as "0" for Same Turbulent Intensities for All Source Types	0 (Recommended and Default Value)

TABLE 5-9 (Continued)

LONGZ Input Parameter	Meaning of Parameter	Optional or Recommended Value of Parameter
ISW(17)	Rural ("0") or Urban ("1") Mode	0 (Recommended and Default Value)
TK	Units Conversion Factor	381.68 (Concentration in ppm)
ZR	Wind Speed Measurement Height above HA (m)	129.1 (Recommended)
HA	Elevation above MSL of Weather Station (m)	3 (Recommended)
GAMMA1	Adiabatic Plume Rise Entrainment Coefficient	0.60 (Recommended and Default Value)
GAMMA2	Stable Plume Rise Entrainment Coefficient	0.66 (Recommended and Default Value)
DECAY	Exponential Decay Coefficient for Physical or Chemical Depletion (sec^{-1})	0 (Recommended and Default Value)
ROTATE	Angular Displacement of Receptor Grid from True North (deg)	0 (Recommended and Default Value)
UTMX	X Origin of Polar Coordinates (m)	0 (Optional)
UTMY	Y Origin of Polar Coordinates (m)	0 (Optional)

bluff of emissions from the short stacks at the Kaiser plant and other tideflats sources probably are overestimated by SHORTZ during hours with moderate or strong winds from the south-southwest or southwest, but are not necessarily overestimated during hours with light southerly winds. On the other hand, our experience in very similar modeling situations (see Appendix H of Bjorklund and Bowers, 1982) suggests that the concentrations calculated on the bluff for emissions from the Tacoma City Light and Kaiser tall stacks during hours with moderate or strong winds from the south-southwest or southwest are likely to be in good agreement with the actual impacts.

SECTION 6

SUGGESTIONS FOR FUTURE WORK

We believe that the interim SHORTZ/LONGZ dispersion model methodology outlined in Section 5 can be improved through analyses of existing data, additional measurements and more detailed model testing. First, because ASARCO inadvertently provided EPA Region 10 with the Benny's (N26th & Pearl) wind data rather than the 46-meter Tower (N26th & Pearl) wind data, the 46-meter Tower wind data were not received in time to be included in our study. We therefore recommend that the 46-meter Tower wind data be evaluated in the same manner as the Benny's wind data to determine if the Tower winds are more representative of transport winds than the Benny's winds. We also suggest that the 1981 McChord Air Force Base cloud-cover data be used with the concurrent PSAPCA N26th & Pearl or ASARCO Benny's wind speeds to assign stability following the Turner (1964) approach because the appropriate wind measurement height for this stability classification scheme is at or near 10 meters. Additionally, we recommend that mixing depths be estimated from the Washington DOE acoustic sounder measurements at Portage Bay for comparison with mixing depths estimated from the concurrent upper-air soundings. If a close correspondence is found between the two sets of mixing depths, the acoustic sounder data could be routinely reduced to obtain valuable information on the depth of the surface mixing layer throughout the day.

The Kaiser SO_2 air quality data provided us with the only indication of the air quality impact within the tideflats and on the bluff northeast of the tideflats of emissions from the existing sources. Because it is our understanding that the Kaiser monitoring program has been terminated, we suggest that PSAPCA consider the possibility of locating an SO_2 air quality monitor north or north-northeast of the Kaiser plant. Also, because the results of our limited SHORTZ calculations for the Kaiser Plant site monitor indicate that our interim modeling methodology may underestimate concentrations near the Kaiser plant due to an overestimation of buoyant plume rise for the dry scrubber stacks, we recommend that this monitor be placed as close to the Kaiser plant as is practical. Air quality monitoring on the bluff following the construction of the Tacoma City Light cogeneration plant and/or the Kaiser plant expansion should provide additional data needed to test model performance. Finally, we are unable to reconcile the SO_2 emissions reported by ASARCO for some of the days during the 1981 air stagnation episodes with the observed SO_2 concentrations. As pointed out by PSAPCA (Carson, 1982), emissions from the ASARCO smelter are possible when the in-stack SO_2 monitor shows zero emissions. We therefore recommend that efforts be made to obtain more detailed information on SO_2 emissions from all of the sources in and adjacent to the tideflats area during the period 23 through 25 October 1981. Special attention should be given to the question of what stack and/or low-level emissions can occur at the ASARCO smelter during hours when the emission rate reported for the Main Stack is zero or very low.

We believe that the above recommendations for future work can possibly be accomplished with the resources currently available to EPA Region 10, the Washington DOE and PSAPCA. In our opinion, the implementation of these recommendations should lead to an improvement in the accuracy of predictions made using the interim SHORTZ/LONGZ air quality model methodology outlined in Section 5. However, it should be recognized that the implementation of the above recommendations will not necessarily result in the optimum SHORTZ/LONGZ model methodology for use in the Tacoma tideflats area. Also, models other than the SHORTZ/LONGZ models may be necessary to address some critical meteorological regimes such as air stagnation episodes. Table 6-1 briefly summarizes the advantages and disadvantages of several possible approaches that could assist in the development of an optimum SO_2 air quality model methodology for the Tacoma tideflats area. Inspection of Table 6-1 indicates that the current major impediment to the development of a model methodology is the very limited knowledge of the spatial and temporal variations of meteorologial conditions and SO_2 air quality within the tideflats area. Thus, all of the possible approaches

TABLE 6-1

ADVANTAGES AND DISADVANTAGES OF POSSIBLE APPROACHES TO AID IN THE DEVELOPMENT OF AN SO_2 AIR QUALITY MODEL METHODOLOGY FOR THE TACOMA TIDEFLATS AREA

Approach	Advantages	Disadvantages
Field Measurement Program to define empirical source-receptor relationships. Inject an inert tracer (for example, SF_6) into emissions from each source, one at a time. Alternately, simultaneously inject multiple inert tracers into emissions from the various sources so that the impacts of the various sources can be distinguished. Compile detailed records of operating conditions and emissions parameters for each source. Make very detailed meteorological and tracer air quality measurements in and adjacent to the tideflats area.	1. Given a sufficient data base, monitoring could be used in place of modeling for the existing sources. 2. New or modified air quality modeling techniques uniquely applicable to the tideflats area could possibly be developed. 3. The resulting data base would be a valuable one for use in model development and evaluation studies.	1. A measurement program of this type would probably cost a million dollars or more. 2. The field measurement program probably would have to cover a period of at least 1 year in order to identify all critical meteorological regimes. 3. Current land use and the topography will make it very difficult to place tracer air quality monitors at all of the desired locations. 4. The cooperation of all of the sources in the tideflats area is necessary. 5. Empirical source-receptor relationships cannot necessarily be extrapolated to new sources with different emissions characteristics.
Numerical Wind Field Models to define wind fields and plume trajectories under critical meteorological conditions.	1. This is a relatively inexpensive approach. 2. This approach may define areas where additional monitoring is needed.	1. Because of the complexity of the terrain and the desired resolution of the wind field, it may be difficult to obtain converged (steady-state) model solutions.

TABLE 6-1 (Continued)

Approach	Advantages	Disadvantages
Numerical Wind Field Models (Continued)	3. This approach may provide qualitative insight into source-receptor relationships under some meteorological conditions. 4. This approach may assist in optimizing meteorological inputs to existing models such as the SHORTZ/LONGZ models.	2. Wind field models will not necessarily apply under all meteorological conditions, especially light wind conditions. 3. The wind measurements required to evaluate and verify the performance of wind field models would have to be collected.
Numerical Dispersion Model such as a variable-trajectory Gaussian puff model to calculate ambient SO_2 concentrations.	1. This approach can consider the variations in space and time of winds, turbulent intensities, mixing depths and other important meteorological parameters. 2. This approach can be used during periods of very light or calm winds.	1. The current meteorological measurements are not sufficient to implement this type of model. 2. The basic time increment might have to be as short as 5 to 10 minutes to address some meteorological conditions such as periods of light and variable winds. 3. The model could be very costly to execute in an operational manner, especially if the interpolated wind fields are required to be mass consistent.
Additional Measurements to define the meteorology and SO_2 air quality of the Tacoma tideflats area.	1. A Doppler acoustic sounder located in the tideflats could in principle measure all SHORTZ inputs without recourse to discrete stability categories.	1. Although this measurement technique appears very promising, we know of no operational studies in which all meteorological inputs were or are measured by a Doppler

TABLE 6-1 (Continued)

Approach	Advantages	Disadvantages
Additional Measurements (Continued)	These inputs include vertical profiles of wind direction, wind speed, the turbulent intensities and the depth of the surface mixing layer. 2. A minimum of three 30-meter towers--with wind, turbulence and temperature instrumentation at the 10-meter and 30-meter levels--located at the center and either side of the tideflats area would provide a better definition of the variation of meteorological conditions with location within the tideflats. 3. Minisonde releases from the tideflats made four times per day (0700, 1300, 1900 and 0100 PST) during a 1-year period could be used to establish a climatological summary of the thermal stratifications within the tideflats and could be compared with acoustic sounder (tideflats and/or Portage Bay) and other measurements. 4. Additional SO_2 air quality monitors within the tideflats (for example, north-northeast or south-southwest of major sources such as Kaiser) and on the bluff	acoustic sounder. The The practicality of this approach can only be determined by experience. 2. Current land use could make it difficult to find representative sites within the tideflats area for acoustic sounders or instrumented meteorological towers. 3. Accurate wind-direction measurements during periods of light winds are difficult, but are necessary if source-receptor relationships are to be understood. 4. Towers with measurement heights above ground level as high as 100 meters will not necessarily define winds at the plume heights for emissions from the taller stacks. 5. A detailed analysis of the measurements will be required to develop or refine an air quality model methodology.

TABLE 6-1 (Continued)

Approach	Advantages	Disadvantages
Additional Measurements (Continued)	to the north-northeast of the two tall stacks in the tideflats area could significantly improve our understanding of the space and time variations of SO_2 concentrations within the tideflats. 5. Accurate estimates of ASARCO stack and low-level SO_2 emissions could help to isolate the effects on air quality of ASARCO emissions from the effects of emissions from the sources within the tideflats.	

in Table 6-1 except the use of a numerical wind field model require additional measurements, and additional measurements are the only means to verify the predictions of a wind field model. Because of the importance of additional measurements, Table 6-1 provides some specific suggestions on the types of measurements that are needed.

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APPENDIX A

MATHEMATICAL MODELS USED TO CALCULATE GROUND-LEVEL CONCENTRATIONS

A.1 INTRODUCTION

The computerized diffusion models described in this appendix fall into two general categories: (1) A short-term model for calculating time-averaged ground-level concentrations for averaging times of 1, 3, 8, and 24 hours; (2) A long-term model for calculating seasonal and annual ground-level concentrations. Both the short term and long-term concentrations models are modified versions of the Gaussian plume model for continuous sources described by Pasquill (1962). In the short-term model, the plume is assumed to have Gaussian vertical and lateral concentration distributions. The long-term model is a sector model similar in form to the Environmental Protection Agency's Climatological Dispersion Model (Calder, 1971) in which the vertical concentration distribution within a sector is rectangular (a smoothing function is used to eliminate sharp discontinuities at the sector boundaries). Vertical plume growth (σ_z) in the short-term and long-term models and lateral plume growth (σ_y) in the short-term model are calculated by using turbulent intensities in simple power-law expressions that include the effects of initial source dimensions. In both the short-term and long-term models, buoyant plume rise is calculated by means of the Briggs (1971; 1972) plume-rise formulas, modified to include the effects of downwash in the lee of the stack during periods when the wind speed at stack height equals or exceeds the stack exit velocity. An exponent law is used to adjust wind speed to the source height for plume-rise calculations and to the plume stabilization height for the concentration calculations. Both the short-term and the long-term models contain provisions to account for the effects of complex terrain.

Table A-1 lists the hourly meteorological inputs required by the short-term concentration model. Lateral and vertical turbulent

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intensities σ'_A and σ'_E may be directly specified or may be assigned on the basis of the Pasquill stability category (see Section 3 of Cramer, et al., 1975). The Pasquill stability cateogry is determined from surface weather observations using the Turner (1964) wind-speed and solar-index values. Mixing depths may be obtained from rawinsonde or pibal measurements, or they may be assigned on the basis of tabulations of the frequency of occurrence of wind speed and mixing depth (available from the National Climatic Center for synoptic rawinsonde stations). Potential temperature gradients may be obtained from measurements or assigned on the basis of climatology.

Table A-2 lists the meteorological inputs required by the long-term concentration model. Joint-frequency distributions of wind-speed and wind-direction categories, classified according to the Pasquill stability categories, are available from the National Climatic Center. Alternately, surface wind observations may be analyzed to generate wind-frequency distributions by time-of-day categories (night, morning, afternoon and evening). Vertical turbulent intensities may be determined from a climatology of actual measurements or may be assigned on the basis of the Pasquill stability categories. Median mixing depths may be determined from the seasonal tabulations of the frequency of occurrence of wind-speed and mixing depth prepared by the National Climatic Center. Vertical potential temperature gradients may be assigned to the combinations of wind-speed and stability or time-of-day categories on the basis of climatology.

Table A-3 lists the source input parameters required by the short-term and long-term diffusion models. As shown by the table, the computerized short-term and long-term models calculate ground-level concentrations produced by emissions from stacks, building vents and roof monitors, and from area sources. Both the short-term and long-term models also use a Cartesian coordinate system (usually the Universal Transverse Mercator system) with the positive X axis directed toward the east and the positive Y axis directed toward the north.

TABLE A-1

HOURLY METEOROLOGICAL INPUTS REQUIRED BY THE SHORT-TERM CONCENTRATION MODEL

Parameter	Definition
$\bar{u}_R$	Mean wind speed at height z_R (m/sec)
θ	Mean wind direction at height z_R (deg)
p	Wind-profile exponent
σ'_A	Wind azimuth-angle standard deviation in radians
σ'_E	Wind elevation-angle standard deviation in radians
T_a	Ambient air temperature (°K)
H_m	Depth of surface mixing layer (m)
$\frac{\partial \theta}{\partial z}$	Vertical potential temperature gradient (°K/m)

TABLE A-2

METEOROLOGICAL INPUTS REQUIRED BY THE LONG-TERM CONCENTRATION MODEL

Parameter	Definition
$f_{i,j,k,\ell}$ (Table)	Frequency distribution of wind-speed and wind-direction categories by stability or time-of-day categories for the ℓ^{th} season
$p_{k,i}$ (Table)	Wind-profile exponent for each stability or time-of-day category and i^{th} wind-speed category
$\sigma'_{E;i,k}$ (Table)	Standard deviation of the wind-elevation angle in radians for the i^{th} wind-speed category and k^{th} stability or time-of-day category
$T_{a;k,\ell}$ (Table)	Ambient air temperature for the k^{th} stability or time-of-day category and ℓ^{th} season (°K)
$\left(\frac{\partial\theta}{\partial z}\right)_{i,k}$ (Table)	Vertical potential temperature gradient for the i^{th} wind-speed category and k^{th} stability or time-of-day category (°K/m)
$H_{m;i,k,\ell}$ (Table)	Median surface mixing depth for the i^{th} wind-speed category, k^{th} stability or time-of-day category and ℓ^{th} season (m)
$\bar{u}\{z_R\}_i$ (Table)	Mean wind speed at height z_R for the i^{th} wind-speed category (m/sec)

TABLE A-3

SOURCE INPUTS REQUIRED BY THE SHORT-TERM AND LONG-TERM CONCENTRATION MODELS

Parameter	Definition
Stacks	
Q	Pollutant emission rate (mass per unit time)
X, Y	X and Y coordinates of the stack (m)
z_s	Elevation above mean sea level of the base of the stack (m)
h	Stack height (m)
v	Actual volumetric emission rate (m^3/sec)
T_s	Stack exit temperature (^oK)
r	Stack inner radius (m)
Building Sources	
Q	Pollutant emission rate (mass per unit time)
X, Y	X and Y coordinates of the center of the building (m)
z_s	Elevation above mean sea level of the base of the building (m)
h	Building height (m)
L	Building length (m)
W	Building width (m)
δ	Angle measured clockwise between north and the long side of the building (deg)
Area Sources	
Q	Pollutant emission rate (mass per unit time)
X, Y	X and Y coordinates of the center of the area source (m)
z_s	Elevation above mean sea level of the area source (m)

TABLE A-3 (Continued)

Parameter	Definition
Area Sources (Continued)	
h	Characteristic vertical dimension of the area source (m)
L	Length of the area source (m)
W	Width of the area source (m)
δ	Angle measured clockwise between north and the long side of the area source (deg)

A.2 PLUME-RISE FORMULAS

The effective stack height H of a buoyant plume is given by the sum of the physical stack height h and the buoyant rise Δh. For an adiabatic or unstable atmosphere, the buoyant rise Δh_N is given by

$$\Delta h_N = \left[\frac{1}{\bar{u}\{h\}} \left(\frac{3F}{2\gamma_1^2} \right)^{1/3} (10h)^{2/3} \right] f \qquad \text{(A-1)}$$

where the expression in the brackets is from Briggs (1971; 1972) and

$\bar{u}\{h\}$ = the mean wind speed at the stack height h (m/sec)
γ_1 = the adiabatic entrainment coefficient ~ 0.6 (Briggs, 1972)
F = The initial buoyancy flux (m^4/sec^3)

$$= \frac{gV}{\pi} \left(1 - \frac{T_a}{T_s} \right) \qquad \text{(A-2)}$$

V = The volumetric emission rate of the stack (m^3/sec)
= $\pi r^2 w$
r = inner radius of stack (m)
w = stack exit velocity (m/sec)
g = the acceleration due to gravity (m/sec^2)
T_a = the ambient air temperature (^oK)
T_s = the stack exit temperature (^oK)

The factor f, which limits the plume rise as the mean wind speed at stack height approaches or exceeds the stack exit velocity, is defined by

$$f = \left\{ \begin{array}{lll} 1 & ; & \bar{u}\,\{h\} \leq w/1.5 \\ \left(\dfrac{3w - 3\bar{u}\{h\}}{w}\right) & ; & w/1.5 < \bar{u}\,\{h\} < w \\ 0 & ; & \bar{u}\,\{h\} \geq w \end{array} \right\} \qquad \text{(A-3)}$$

The empirical correction factor f is generally not applied to stacks with Froude numbers less than about unity. The corresponding Briggs (1971) rise formula for a stable atmosphere (potential temperature gradient greater than zero) is

$$\Delta h_s = \left\{ \begin{array}{ll} \left[\dfrac{6F}{\bar{u}\{h\}\gamma_2^{\,2}\, S}\right]^{1/3} & ;\pi\ \bar{u}\{h\}\ S^{-1/2} < 10h \\ \left[\dfrac{3F}{\bar{u}\{h\}\gamma_2^{\,2}\, S}\left(1 - \cos\left(\dfrac{10S^{1/2}h}{\bar{u}\{h\}}\right)\right)\right]^{1/3} & ;\pi\ \bar{u}\{h\}\ S^{-1/2} \geq 10h \end{array} \right\} f \qquad \text{(A-4)}$$

where

γ_2 = the stable entrainment coefficient ~ 0.66 (Briggs, 1972)

$S = \dfrac{g}{T_a}\dfrac{\partial\theta}{\partial z}$

$\dfrac{\partial\theta}{\partial z}$ = vertical potential temperature gradient ($^{\circ}$K/m)

The entrainment coefficients γ_1 and γ_2 are based on the suggestions of Briggs (1972). It should be noted that Equation (A-4) does not permit the calculated stable rise Δh_s to exceed the adiabatic rise Δh_N as the atmosphere approaches a neutral stratification ($\partial\theta/\partial z$ approaches 0). A procedure of this type is recommended by Briggs (1972).

A.3 SHORT-TERM CONCENTRATION MODEL

A.3.1 Elevated Sources

The atmospheric dispersion model used to calculate hourly average ground-level concentrations downwind from an elevated continuous source is given by

$$\{\chi\}x,y = \frac{K\ Q}{\pi\ \bar{u}\{H\}\sigma_y\ \sigma_z}\ \{\text{Vertical Term}\}\ \{\text{Lateral Term}\}\ \{\text{Decay Term}\} \quad \text{(A-5)}$$

where

K = scaling coefficient to convert input parameters to dimensionally consistent units

Q = source emission rate (mass per unit time)

$\bar{u}\{H\}$ = mean wind speed at the plume stabilization height H (m/sec)

σ_y,σ_z = standard deviations of the lateral and vertical concentration distributions at downwind distance x (m)

The Vertical Term refers to the plume expansion in the vertical or z direction and includes a multiple reflection term that limits cloud growth to the surface mixing layer.

$$\{\text{Vertical Term}\} = \left\{\exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] + \sum_{n=1}^{\infty}\left[\exp\left[-\frac{1}{2}\left(\frac{2n\ H_m + H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{2n\ H_m - H}{\sigma_z}\right)^2\right]\right]\right\} \quad \text{(A-6)}$$

where H_m is the depth of the surface mixing layer. The exponential terms in the infinite series in Equation (A-6) rapidly approach zero near the source. At the downwind distance where the exponential terms exceed exp(-10) for n equal 3, the plume has become approximately uniformly mixed within the surface mixing layer. In order to shorten computer computation time, Equation (A-6) is changed to the form

$$\{\text{Vertical Term}\} = \frac{\sqrt{2\pi}\,\sigma_z}{2H_m} \qquad \text{(A-7)}$$

beyond this point. Equation (A-7) changes the form of the vertical concentration distribution from Gaussian to rectangular. If H exceeds H_m, the Vertical Term is set equal to zero which results in a zero value for the ground-level concentration.

The Lateral Term refers to the crosswind expansion of the plume and is given by the expression

$$\{\text{Lateral Term}\} = \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \qquad \text{(A-8)}$$

where y is the crosswind distance from the plume centerline to the point at which concentration is calculated.

The Decay Term, which accounts for the possibility of pollutant removal by physical or chemical processes, is of the form

$$\{\text{Decay Term}\} = \exp\left[-\psi\, x/\bar{u}\{H\}\right] \qquad \text{(A-9)}$$

where

ψ = the washout coefficient Λ (sec^{-1}) for precipitation scavenging

$= \frac{0.692}{T_{1/2}}$, where $T_{1/2}$ is the pollutant half life in seconds for physical or chemical removal

$=$ 0 for no depletion (ψ is automatically set to zero by the computer program unless otherwise specified)

In the model calculations, the observed mean wind speed $\bar{u}_R$ is adjusted from the measurement height z_R to the source height h for plume-rise calculations and to the stabilization height H for the concentration calculations by a wind-profile exponent law

$$\bar{u}\{z\} = \bar{u}\{z_R\} \left(\frac{z}{z_R}\right)^p \qquad \text{(A-10)}$$

The exponent p, which is assigned on the basis of atmospheric stability, ranges from about 0.1 for very unstable conditions to about 0.4 for very stable conditions.

According to the derivation in the report by Cramer, et al. (1972), the standard deviation of the lateral concentration distribution σ_y is given by the expression

$$\sigma_y\{x\} = \sigma'_A \, x_{ry} \left[\frac{x + x_y - x_{ry}(1-\alpha)}{\alpha x_{ry}}\right]^\alpha \qquad \text{(A-11)}$$

$$x_y = \begin{cases} \dfrac{\sigma_{yR}}{\sigma'_A} - x_R & ; \dfrac{\sigma_{yR}}{\sigma'_A} \leq x_{ry} \\[2ex] \alpha x_{ry} \left(\dfrac{\sigma_{yR}}{x_{ry}\,\sigma'_A}\right)^{1/\alpha} - x_R + x_{ry}(1-\alpha) & ; \dfrac{\sigma_{yR}}{\sigma'_A} > x_{ry} \end{cases} \qquad \text{(A-12)}$$

where

σ'_A = the standard deviation of the wind-azimuth angle in radians

x_{ry} = distance over which rectilinear plume expansion occurs downwind from an ideal point source (~50 meters)

σ_{yR} = the standard deviation of the lateral concentration distribution at downwind distance x_R (m)

α = the lateral diffusion coefficient (~0.9)

The virtual distance x_y is not permitted to be less than zero. The lateral turbulent intensity σ'_A may be specified directly or may be assigned on the basis of the Pasquill stability category.

Following the derivation of Cramer, et al. (1972) and setting the vertical diffusion coefficient β equal to unity, the standard deviation of the vertical concentration distribution σ_z is given by the expression

$$\sigma_z\{x\} = \sigma'_E \left(x + x_z\right) \tag{A-13}$$

$$x_z = \begin{cases} \dfrac{\sigma_{zR}}{\sigma'_E} - x_R & ; \dfrac{\sigma_{zR}}{\sigma'_E} \geq x_R \\ \\ 0 & ; \dfrac{\sigma_{zR}}{\sigma'_E} < x_R \end{cases} \tag{A-14}$$

where

σ'_E = standard deviation of the wind-elevation angle in radians

σ_{zR} = the standard deviation of the vertical concentration distribution at downwind distance x_R (m)

The vertical turbulent intensity σ'_E may also be obtained from direct measurements or may be assigned according to the Pasquill stability categories. When σ'_E values corresponding to the Pasquill stability categories are entered in Equation (A-13), the resulting curves will differ from the corresponding Pasquill-Gifford curves in that Equation (A-13) assumes rectilinear expansion at all downwind distances. Thus, σ_z values obtained from Equation (A-13) will be smaller than the values obtained from the Pasquill-Gifford A and B curves and larger than the values obtained from the D, E and F curves at long downwind distances. However, the multiple reflection term in Equation (A-6), which confines the plume to the surface mixing layer, accounts for the behavior of the D, E and F curves (decrease in the expansion rate with distance) in a manner that may be related to the meteorology of the area.

Following the recommendations of Briggs (1972), the lateral and vertical standard deviations of a stabilized buoyant plume are defined by

$$\sigma_{yR} = \sigma_{zR} = \frac{0.5\ \Delta h}{2.15} \qquad \text{(A-15)}$$

The downwind distance to stabilization x_R is given by

$$x_R = \left\{ \begin{array}{lll} 10h & ; & \frac{\partial\theta}{\partial z} \le 0 \\ \pi\ \bar{u}\{h\}\ S^{-1/2} & ; & \frac{\partial\theta}{\partial z} > 0 \text{ and } \pi\ \bar{u}\{h\}\ S^{-1/2} < 10h \\ 10h & ; & \frac{\partial\theta}{\partial z} > 0 \text{ and } \pi\ \bar{u}\{h\}\ S^{-1/2} \ge 10h \end{array} \right\} \qquad \text{(A-16)}$$

A.3.2 Application of the Short-Term Model to Low-level Emissions

The short-term diffusion model in Section A.3.1 may be used to calculate ground-level concentrations resulting from low-level emissions such as losses through building vents. These emissions are rapidly distributed by the cavity circulation of the building wake and quickly assume the dimensions of the building. Ground-level concentrations are calculated by setting the buoyancy parameter F equal to zero. The standard deviation of the lateral concentration distribution at the source σ_{yo} is defined by the building crosswind dimension y_o divided by 4.3. The standard deviation of the vertical concentration distribution at the source is obtained by dividing the building height by 2.15. The initial dimensions σ_{yo} and σ_{zo} are assumed to be applicable at the downwind edge of the building. These procedures are in good agreement with the results of recent wind-tunnel experiments reported by Huber and Snyder (1976). It should be noted that separate turbulent intensities σ'_A and σ'_E may be defined for the low-level sources to account for the effects of surface roughness elements and heat sources.

A.3.3 Short-Term Concentration Model for Area Sources

The atmospheric dispersion model used to calculate ground-level concentrations at downwind distance x from the downwind edge of an area source is given by the expression

$$\chi\{x,\ y\} = \frac{K\ Q}{\sqrt{2\pi}\ \bar{u}\{h\}\ \sigma_z\{x\}\ y_o}\ \{\text{Vertical Term}\}\ \{\text{Lateral Term}\}\ \{\text{Decay Term}\} \qquad \text{(A-17)}$$

where

Q = area source strength in units of mass per unit time

y_o = crosswind source dimension (m)

$$\sigma_z\{x\} = \begin{cases} \dfrac{\sigma'_E\, x_o}{\ln\left[\dfrac{\sigma'_E(x+x_o)+h}{\sigma'_E(x)+h}\right]} & ; \quad x < 3\ x_o \\ \\ \sigma'_E(x+x_o/2)+h & ; \quad x \geq 3\ x_o \end{cases} \qquad \text{(A-18)}$$

x_o = alongwind dimension of the area source (m)
h = the characteristic height of the area source (m)

The Vertical Term for an area source is given by

$$\{\text{Vertical Term}\} = \begin{cases} 1+2\displaystyle\sum_{n=1}^{3} \exp\left[-\frac{1}{2}\left(\frac{2n\ H_m}{\sigma_x\{x\}}\right)^2\right] & ; \quad \dfrac{1}{2}\left(\dfrac{6H_m}{\sigma_z\{x\}}\right)^2 \geq 10 \\ \\ \dfrac{\sqrt{2\pi}\ \sigma_z\{x\}}{2H_m} & ; \quad \dfrac{1}{2}\left(\dfrac{6H_m}{\sigma_z\{x\}}\right)^2 < 10 \end{cases} \qquad \text{(A-19)}$$

The Lateral Term is given by the expression

$$\{\text{Lateral Term}\} = \left\{\text{erf}\left[\frac{y_o/2 + y}{\sqrt{2}\ \sigma_y\{x\}}\right] + \text{erf}\left[\frac{y_o/2 - y}{\sqrt{2}\ \sigma_y\{x\}}\right]\right\} \qquad \text{(A-20)}$$

where

y_o = crosswind dimension of the area source (m)
y = crosswind distance from the centerline of the area source (m)

and

$$\sigma_y\{x\} = \sigma'_A \ (x+x_o/2) \tag{A-21}$$

The Decay Term is given by Equation (A-9) above.

The concentration at points interior to the area source is given by

$$\chi\{x'\} = \frac{2\ K\ Q}{\sqrt{2\pi}\ \bar{u}\{h\}\ x_o\ y_o\ \sigma'_E} \left\{ \ln \left[\frac{\sigma'_E\ (x'+1)+h}{\sigma'_E + h} \right] \right\} \{\text{Vertical Term}\} \tag{A-22}$$

where

x' = distance downwind from the upwind edge of the area source (m)

A.4 LONG-TERM CONCENTRATION MODEL

A.4.1 Elevated Sources

The atmospheric dispersion model for elevated point and volume sources is similar in form to the Air Quality Display Model (Environmental Protection Agency, 1969) and the Climatological Dispersion Model (Calder, 1971). In the model, the area surrounding a continuous source of pollutants is divided into sectors of equal angular width corresponding to the class intervals of the seasonal and annual frequency distributions of wind direction. The emission rate during a season or year is partitioned according to the relative wind-direction frequencies. Ground-level concentration fields for each source are translated to a common reference coordinate grid system and summed to obtain the total due to all emissions. For a single source, the mean seasonal concentration at a point (r, θ) is given by

$$\chi_\ell\{r,\theta\} = \frac{2\,K\,Q}{\sqrt{2\pi}\;r\;\Delta\theta'} \sum_{i,j,k} \left[\frac{f_{i,j,k,\ell}}{\bar{u}_i\left\{H_{i,k,\ell}\right\}\,\sigma_{z;i,k,\ell}}\; S\{\theta\}\, V_{i,k,\ell} \right. \tag{A-23}$$

$$\left. \exp\left[-\,\psi\; r/\bar{u}_i\; H_{i,k,\ell}\}\right]\right]$$

$$V_{i,k,\ell} = \exp\left[-\frac{1}{2}\left(\frac{H_{i,k,\ell}}{\sigma_{z;i,k,\ell}}\right)^2\right] + \sum_{n=1}^{\infty}\left\{\exp\left[-\frac{1}{2}\left(\frac{2n\;H_{m;i,k,\ell}-H_{i,k,\ell}}{\sigma_{z;i,k,\ell}}\right)^2\right]\right. \tag{A-24}$$

$$\left. +\exp\left[-\frac{1}{2}\left(\frac{2n\;H_{m;i,k,\ell}+H_{i,k,\ell}}{\sigma_{z;i,k,\ell}}\right)^2\right]\right\}$$

where

$f_{i,j,k,\ell}$ = frequency of occurrence of the i^{th} wind-speed category, j^{th} wind-direction category and k^{th} stability or time-of-day category for the ℓ^{th} season

$\Delta\theta'$ = the sector width in radians

$S\{\theta\}$ = a smoothing function

$$S\{\theta\} = \begin{cases} \dfrac{\Delta\theta' - |\theta_j' - \theta'|}{\Delta\theta'} & ; \quad |\theta_j' - \theta'| \le \Delta\theta' \\[2ex] 0 & ; \quad |\theta_j' - \theta'| > \Delta\theta' \end{cases} \tag{A-25}$$

θ_j' = the angle measured in radians from north to the centerline of the j^{th} wind-direction sector

θ' = the angle measured in radians from north to the point (r,θ)

As with the short-term model, the Vertical Term given by Equation (A-24) is changed to the form

$$V_{i,k,\ell} = \frac{\sqrt{2\pi}\,\sigma_{z;i,k,\ell}}{2H_{m;i,k,\ell}} \tag{A-26}$$

when the exponential terms in Equation (A-24) exceed exp(-10) for n equal 3. The remaining terms in Equations (A-23) are identical to those previously defined in Section A.3.1 for the short-term model, except that the turbulent intensities and potential temperature gradients may be separately assigned to each wind-speed and/or stability (or time-of-day) category; the ambient air temperatures may be separately assigned to each stability (or time-of-day) category for each season; and the surface mixing depths may be separately assigned to each wind-speed and/or stability (or time-of-day) category for each season.

As shown by Equation (A-25), the rectangular concentration distribution within a given angular sector is modified by the function $S\{\theta\}$ which smoothes discontinuities in the concentration at the boundaries of adjacent sectors. The centerline concentration in each sector is unaffected by contributions from adjacent sectors. At points off the sector centerline, the concentration is weighted function of the concentration at the centerline of the sector in which the calculation is being made and the concentration at the centerline of the nearest adjoining sector.

The mean annual concentration at the point (r,θ) is calculated from the seasonal concentrations using the expression

$$\chi_a\{r,\theta\} = \frac{1}{4}\sum_{\ell=1}^{4} \chi_\ell\{r,\theta\} \tag{A-27}$$

A.4.2 Application of the Long-Term Model to Low-Level Emissions

Long-term ground-level concentrations produced by low-level emissions are calculated from Equation (A-23) by setting the buoyancy parameter F equal to zero. The standard deviation of the vertical concentration distribution at the downwind edge of the building σ_{zo} is defined as the building height divided by 2.15. Separate vertical turbulent intensities σ'_E may be defined for the low-level sources to account for the effects of surface heat sources and roughness elements. A virtual point source is used to account for the initial lateral dimension of the source in a manner identical to that described below for area sources.

A.4.3 Long-Term Concentration Model for Area Sources

The mean seasonal concentration at downwind distance r with respect to the center of an area source is given by the expression

$$\chi_{\ell}\{r > r_o\} = \frac{2\ K\ Q}{\sqrt{2\pi}\ R\ \Delta\theta'} \left\{ \sum_{i,j,k} \left[\frac{f_{i,j,k,\ell}}{\bar{u}_i\{h\}\ \sigma_{z;i,k}} \ S\{\theta\}\ V_{i,k,\ell} \right] \exp\left[-\psi\left(r' - r_o\right)/\bar{u}_i\{h\} \right] \right\} \tag{A-28}$$

where

R = radial distance from the virtual point source to the receptor

$= \left(\left(r' + x_y\right)^2 + y^2\right)^{1/2}$

r' = distance from source center to receptor, measured along the sector centerline (m)

r_o = effective source radius (m)

y = lateral distance from the sector centerline to the receptor (m)

x_y = lateral virtual distance (m)

$$= r_o \cot \frac{\Delta\theta'}{2} \qquad \text{(A-29)}$$

$$\sigma_{z;i,k} = \left\{ \begin{array}{ll} \dfrac{2\,\sigma'_{E;i,k}\; r_o}{\ln\left[\dfrac{\sigma'_{E;i,k}(r'+r_o) + h}{\sigma'_{E;i,k}(r'-r_o) + h}\right]} & ;\; r_o < r' < 6r_o \\ \\ \sigma'_{E;i,k} r' + h & ;\; r' \geq 6r_o \end{array} \right\} \qquad \text{(A-30)}$$

$$V_{i,k,\ell} = \left\{ \begin{array}{ll} 1+2\displaystyle\sum_{n=1}^{3} \exp\left[-\frac{1}{2}\left(\frac{2n\; H_{m;i,k,\ell}}{\sigma_{z;i,k}}\right)^2\right] & ;\; \dfrac{1}{2}\left(\dfrac{6H_{m;i,k,\ell}}{\sigma_{z;i,k}}\right)^2 \geq 10 \\ \\ \dfrac{\sqrt{2\pi}\;\sigma_{z;i,k}}{H_{m;i,k,\ell}} & ;\; \dfrac{1}{2}\left(\dfrac{6H_{m;i,k,\ell}}{\sigma_{z;i,k}}\right)^2 < 10 \end{array} \right\} \qquad \text{(A-31)}$$

and the remaining parameters are identical to those previously defined.

For points interior to the area source, the seasonal average concentration is given by the expression:

$$\chi_\ell\{r \leq r_o\} = \frac{2\;K\;Q}{\sqrt{2\pi}\;x_o\;y_o} \sum_{i,j,k} \left[\frac{f_{i,j,k,\ell}}{\bar{u}_i\{h\}\;\sigma'_{E;i,k}} \ln\left[\frac{\sigma'_{E;i,k}(r''+1) + h}{\sigma'_{E;i,k} + h}\right] V_{i,k,\ell} \right] \qquad \text{(A-32)}$$

where

r'' = the downwind distance, measured along the sector centerline from the upwind edge of the area source (m)

A.5 APPLICATION OF THE SHORT-TERM AND LONG-TERM CONCENTRATION MODELS IN COMPLEX TERRAIN

The short-term and long-term concentration models described in Sections A.3 and A.4 are strictly applicable only for flat terrain where the base of the stack (or the building source) and the ground surface downwind from the source are at the same elevation. However, both models may also be applied to complex terrain by defining effective stabilization heights and mixing depths. The following assumptions are made in the model calculations for complex terrain:

- The top of the surface mixing layer extends over the calculation grid at a constant height above mean sea level
- Ground-level concentrations at all grid points above the top of the surface mixing layer are zero
- Plumes that stabilize above the top of the surface mixing layer do not contribute to ground-level concentrations at any grid point (this assumption also applies to flat terrain)

In order to determine whether the stabilized plume is contained within the surface mixing layer, it is necessary to calculate the mixing depth $H_m^*\{z_s\}$ at the source from the relationship

$$H_m^*\{z_s\} = \left(H_m + z_a - z_s\right) \qquad \text{(A-33)}$$

where

H_m = the depth of the surface mixing layer measured at a point with elevation z_a above mean sea level

z_s = the height above mean sea level of the source

Equation (A-33) is represented schematically in Figure A-1. As shown by the figure, the actual top of the surface mixing layer is assumed to remain at a constant elevation above mean sea level. If the height H of the stabilized plume above the base of the stack is less than or equal to $H_m^*\{z_s\}$, the plume is defined to be contained within the surface mixing layer.

The height H_o of the stabilized plume above mean sea level is given by the sum of the height H of the stabilized plume above the base of the stack and the elevation z_s of the base of the stack. At any elevation z above mean sea level, the effective height $H'\{z\}$ of the plume centerline above the terrain is then given by

$$H'\{z\} = \begin{Bmatrix} H_o - z \;; & H_o - z \geq 0 \\ \\ 0 \;; & H_o - z < 0 \end{Bmatrix} \tag{A-34}$$

The effective mixing depth $H_m'\{z\}$ above a point at elevation z above mean sea level is defined by

$$H_m'\{z\} = \begin{Bmatrix} H_m \;; & z \geq z_a \\ \\ H_m + z_a - z \;; & z < z_a \end{Bmatrix} \tag{A-35}$$

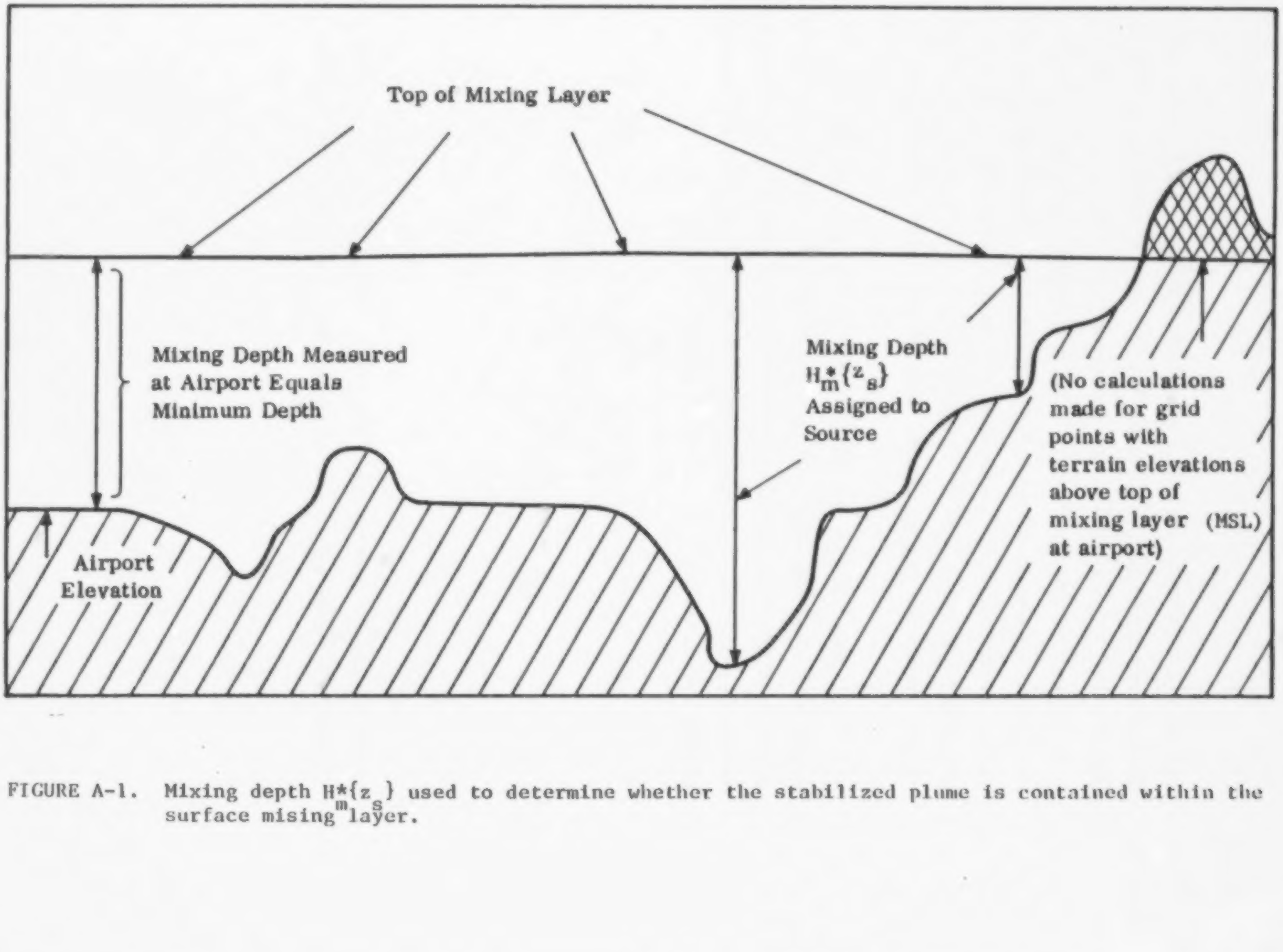
Top of Mixing Layer
Mixing Depth Measured at Airport Equals Minimum Depth
Mixing Depth $H_m^*\{z_s\}$ Assigned to Source
(No calculations made for grid points with terrain elevations above top of mixing layer (MSL) at airport)
Airport Elevation

FIGURE A-1. Mixing depth $H_m^*\{z_s\}$ used to determine whether the stabilized plume is contained within the surface mising layer.

Figure A-2 illustrates the assumptions implicit in Equation (A-35). For grid points at elevations below the airport elevation, the effective mixing depth $H_m'\{z\}$ is allowed to increase in a manner consistent with Figure A-1. However, in order to prevent a physically unrealistic compression of plumes as they pass over elevated terrain, the effective mixing depth is not permitted to be less than the mixing depth measured at the airport. It should be noted that the concentration is set equal to zero for grid points above the actual top of the mixing layer (see Figure A-1).

The terrain adjustment procedures also assume that the mean wind speed at any given height above sea level is constant. Thus, the wind speed $\bar{u}_R$ above the surface at a point with elevation z_a above mean sea level is adjusted to the stack height for the plume-rise calculations by the relationship

$$\bar{u}\{h\} = \begin{cases} \bar{u}_R\left(\dfrac{h_o - z_a}{z_R}\right)^p & ; \quad h_o \geq z_a + z_R \\ \bar{u}_R & ; \quad h_o < z_a + z_R \end{cases} \qquad \text{(A-36)}$$

where h_o is the height above mean sea level of the top of the stack. Similarly, the wind speed $\bar{u}\{H\}$ used in the concentration calculations is given by

$$\bar{u}\{H\} = \begin{cases} \bar{u}_R\left(\dfrac{H_o - z_a}{z_R}\right)^p & ; \quad H_o \geq z_a + z_R \\ \bar{u}_R & ; \quad H_o < z_a + z_R \end{cases} \qquad \text{(A-37)}$$

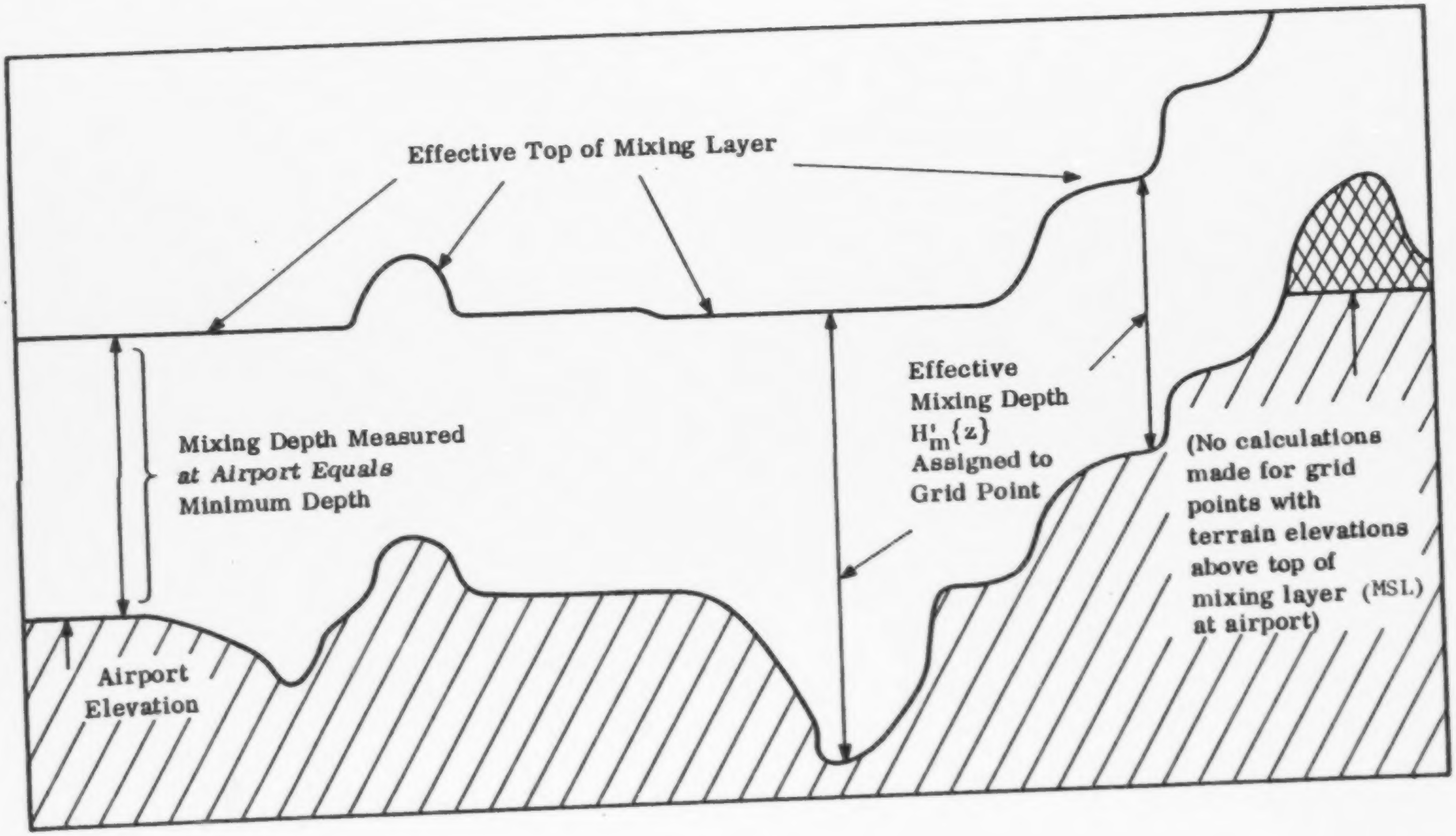
Effective Top of Mixing Layer
Mixing Depth Measured *at Airport Equals* Minimum Depth
Airport Elevation
Effective Mixing Depth $H'_m\{z\}$ Assigned to Grid Point
(No calculations made for grid points with terrain elevations above top of mixing layer (MSL) at airport)

FIGURE A-2. Effective mixing depth $H'_m\{z\}$assigned to grid points for the concentration calculations.

APPENDIX B

RECEPTOR INPUTS FOR THE TACOMA TIDEFLATS AREA

As discussed in Section 5.1, the maximum SO_2 air quality impacts of emissions from the existing and proposed sources located in and adjacent to the Tacoma tideflats Area can be expected within the area with Universal Transverse Mercator (UTM) X coordinates ranging from 537 to 552 kilometers and UTM Y coordinates ranging from 5,230 to 5,242 kilometers. This appendix gives the elevations in meters above mean sea level of receptors which cover this area at 500-meter intervals in a Cartesian coordinate system. Note that UTM X and Y coordinates in units of meters rather than in units of kilometers are required for SHORTZ/LONGZ calculations.

TABLE B-1.

UTM X (METERS)	UTM Y (METERS)	ELEV. (METERS)	UTM X (METERS)	UTM Y (METERS)	ELEV. (METERS)
537000	5230000	67	537500	5230000	73
538000	5230000	88	538500	5230000	91
539000	5230000	73	539500	5230000	91
540000	5230000	98	540500	5230000	104
541000	5230000	107	541500	5230000	107
542000	5230000	107	542500	5230000	104
543000	5230000	91	543500	5230000	67
544000	5230000	82	544500	5230000	85
545000	5230000	52	545500	5230000	67
546000	5230000	43	546500	5230000	52
547000	5230000	6	547500	5230000	3
548000	5230000	3	548500	5230000	6
549000	5230000	6	549500	5230000	6
550000	5230000	9	550500	5230000	9
551000	5230000	9	551500	5230000	9
552000	5230000	12	537000	5230500	64
537500	5230500	99	538000	5230500	94
538500	5230500	94	539000	5230500	85
539500	5230500	73	540000	5230500	94
540500	5230500	107	541000	5230500	110
541500	5230500	104	542000	5230500	104
542500	5230500	101	543000	5230500	61
543500	5230500	91	544000	5230500	91
544500	5230500	85	545000	5230500	30
545500	5230500	61	546000	5230500	12
546500	5230500	37	547000	5230500	5
547500	5230500	6	548000	5230500	6
548500	5230500	6	549000	5230500	6
549500	5230500	6	550000	5230500	6
550500	5230500	6	551000	5230500	5
551500	5230500	9	552000	5230500	83
537000	5231000	70	537500	5231000	83
538000	5231000	91	538500	5231000	94
539000	5231000	104	539500	5231000	98
540000	5231000	75	540500	5231000	76
541000	5231000	75	541500	5231000	75
542000	5231000	73	542500	5231000	73
543000	5231000	67	543500	5231000	82
544000	5231000	89	544500	5231000	73
545000	5231000	21	545500	5231000	37
546000	5231000	5	546500	5231000	5
547000	5231000	5	547500	5231000	6
548000	5231000	6	548500	5231000	6
549000	5231000	6	549500	5231000	6
550000	5231000	6	550500	5231000	6

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TABLE B-1.

UTM X (METERS)	UTM Y (METERS)	ELEV. (METERS)	UTM X (METERS)	UTM Y (METERS)	ELEV. (METERS)
551000	5231000	5	551500	5231000	67
552000	5231000	94	537000	5231500	79
537500	5231500	94	538000	5231500	89
538500	5231500	88	539000	5231500	113
539500	5231500	104	540000	5231500	110
540500	5231500	116	541000	5231500	110
541500	5231500	107	542000	5231500	107
542500	5231500	52	543000	5231500	27
543500	5231500	34	544000	5231500	34
544500	5231500	27	545000	5231500	12
545500	5231500	24	546000	5231500	5
546500	5231500	6	547000	5231500	5
547500	5231500	5	548000	5231500	5
548500	5231500	6	549000	5231500	6
549500	5231500	5	550000	5231500	5
550500	5231500	6	551000	5231500	6
551500	5231500	53	552000	5231500	64
537000	5232000	91	537500	5232000	94
538000	5232000	110	538500	5232000	91
539000	5232000	122	539500	5232000	110
540000	5232000	110	540500	5232000	116
541000	5232000	119	541500	5232000	110
542000	5232000	107	542500	5232000	43
543000	5232000	9	543500	5232000	6
544000	5232000	6	544500	5232000	5
545000	5232000	5	545500	5232000	5
546000	5232000	6	546500	5232000	5
547000	5232000	6	547500	5232000	5
548000	5232000	6	548500	5232000	6
549000	5232000	5	549500	5232000	6
550000	5232000	6	550500	5232000	6
551000	5232000	18	551500	5232000	70
552000	5232000	91	537000	5232500	85
537500	5232500	94	538000	5232500	94
538500	5232500	119	539000	5232500	116
539500	5232500	119	540000	5232500	110
540500	5232500	119	541000	5232500	119
541500	5232500	113	542000	5232500	94
542500	5232500	37	543000	5232500	6
543500	5232500	5	544000	5232500	5
544500	5232500	3	545000	5232500	3
545500	5232500	3	546000	5232500	3
546500	5232500	3	547000	5232500	3
547500	5232500	6	548000	5232500	6
548500	5232500	3	549000	5232500	3

TABLE B-1.

UTM X (METERS)	UTM Y (METERS)	ELEV. (METERS)	UTM X (METERS)	UTM Y (METERS)	ELEV. (METERS)
549500	5232500	3	550000	5232500	18
550500	5232500	6	551000	5232500	6
551500	5232500	61	552000	5232500	94
537000	5233000	91	537500	5233000	94
539000	5233000	101	538500	5233000	125
539000	5233000	119	539500	5233000	115
540000	5233000	113	540500	5233000	113
541000	5233000	116	541500	5233000	107
542000	5233000	91	542500	5233000	34
543000	5233000	0	543500	5233000	3
544000	5233000	6	544500	5233000	3
545000	5233000	3	545500	5233000	3
546000	5233000	3	546500	5233000	3
547000	5233000	3	547500	5233000	3
549000	5233000	3	548500	5233000	3
549000	5233000	3	549500	5233000	6
550000	5233000	67	550500	5233000	9
551000	5233000	6	551500	5233000	43
552000	5233000	79	537000	5233500	110
537500	5233500	98	539000	5233500	110
538500	5233500	113	539000	5233500	113
539500	5233500	119	540000	5233500	113
540500	5233500	113	541000	5233500	113
541500	5233500	104	542000	5233500	88
542500	5233500	37	543000	5233500	0
543500	5233500	3	544000	5233500	3
544500	5233500	3	545000	5233500	3
545500	5233500	3	546000	5233500	3
546500	5233500	3	547000	5233500	3
547500	5233500	3	549000	5233500	3
549500	5233500	3	549000	5233500	3
549500	5233500	79	550000	5233500	79
550500	5233500	6	551000	5233500	12
551500	5233500	43	552000	5233500	73
537000	5234000	119	537500	5234000	113
538000	5234000	110	538500	5234000	110
539000	5234000	110	539500	5234000	110
540000	5234000	110	540500	5234000	113
541000	5234000	110	541500	5234000	98
542000	5234000	91	542500	5234000	6
543000	5234000	3	543500	5234000	3
544000	5234000	3	544500	5234000	3
545000	5234000	3	545500	5234000	3
546000	5234000	3	546500	5234000	3
547000	5234000	3	547500	5234000	3

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TABLE B-1.

UTM X (METERS)	UTM Y (METERS)	ELEV. (METERS)	UTM X (METERS)	UTM Y (METERS)	ELEV. (METERS)
549000	5234000	3	548500	5234000	3
549000	5234000	37	549500	5234000	125
550000	5234000	49	550500	5234000	18
551000	5234000	21	551500	5234000	52
552000	5234000	49	537000	5234500	110
537500	5234500	113	538000	5234500	110
538500	5234500	113	539000	5234500	110
539500	5234500	107	540000	5234500	101
540500	5234500	107	541000	5234500	94
541500	5234500	91	542000	5234500	76
542500	5234500	0	543000	5234500	0
543500	5234500	3	544000	5234500	3
544500	5234500	3	545000	5234500	3
545500	5234500	3	546000	5234500	3
546500	5234500	3	547000	5234500	3
547500	5234500	3	548000	5234500	3
548500	5234500	3	549000	5234500	59
549500	5234500	122	550000	5234500	73
550500	5234500	24	551000	5234500	24
551500	5234500	70	552000	5234500	64
537000	5235000	113	537500	5235000	122
538000	5235000	110	538500	5235000	107
539000	5235000	107	539500	5235000	98
540000	5235000	91	540500	5235000	67
541000	5235000	64	541500	5235000	67
542000	5235000	0	542500	5235000	0
543000	5235000	0	543500	5235000	0
544000	5235000	3	544500	5235000	3
545000	5235000	3	545500	5235000	0
546000	5235000	3	546500	5235000	3
547000	5235000	3	547500	5235000	0
549000	5235000	3	548500	5235000	61
549000	5235000	122	549500	5235000	113
550000	5235000	110	550500	5235000	24
551000	5235000	15	551500	5235000	58
552000	5235000	73	537000	5235500	129
537500	5235500	116	538000	5235500	107
538500	5235500	101	539000	5235500	98
539500	5235500	91	540000	5235500	70
540500	5235500	21	541000	5235500	6
541500	5235500	0	542000	5235500	0
542500	5235500	0	543000	5235500	0
543500	5235500	0	544000	5235500	0
544500	5235500	3	545000	5235500	0
545500	5235500	3	546000	5235500	3

TABLE B-1.

UTM X (METERS)	UTM Y (METERS)	ELEV. (METERS)	UTM X (METERS)	UTM Y (METERS)	ELEV. (METERS)
546500	5235500	3	547000	5235500	0
547500	5235500	73	548000	5235500	61
548500	5235500	122	549000	5235500	125
549500	5235500	122	550000	5235500	110
550500	5235500	55	551000	5235500	30
551500	5235500	24	552000	5235500	70
537000	5236000	131	537500	5236000	110
538000	5236000	101	538500	5236000	91
539000	5236000	85	539500	5236000	18
540000	5236000	3	540500	5236000	0
541000	5236000	0	541500	5236000	0
542000	5236000	0	542500	5236000	0
543000	5236000	0	543500	5236000	0
544000	5236000	0	544500	5236000	0
545000	5236000	3	545500	5236000	3
546000	5236000	0	546500	5236000	3
547000	5236000	37	547500	5236000	107
548000	5236000	67	548500	5236000	123
549000	5236000	128	549500	5236000	122
550000	5236000	98	550500	5236000	67
551000	5236000	53	551500	5236000	43
552000	5236000	73	537000	5236500	94
537500	5236500	98	538000	5236500	98
538500	5236500	91	539000	5236500	79
539500	5236500	0	540000	5236500	0
540500	5236500	0	541000	5236500	0
541500	5236500	0	542000	5236500	0
542500	5236500	0	543000	5236500	0
543500	5236500	0	544000	5236500	0
544500	5236500	0	545000	5236500	0
545500	5236500	24	546000	5236500	30
546500	5236500	37	547000	5236500	110
547500	5236500	123	548000	5236500	122
548500	5236500	125	549000	5236500	119
549500	5236500	110	550000	5236500	98
550500	5236500	73	551000	5236500	67
551500	5236500	58	552000	5236500	73
537000	5237000	83	537500	5237000	85
538000	5237000	85	538500	5237000	67
539000	5237000	0	539500	5237000	0
540000	5237000	0	540500	5237000	0
541000	5237000	0	541500	5237000	0
542000	5237000	0	542500	5237000	0
543000	5237000	0	543500	5237000	0
544000	5237000	0	544500	5237000	0

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TABLE B-1.

UTM X (METERS)	UTM Y (METERS)	ELEV. (METERS)	UTM X (METERS)	UTM Y (METERS)	ELEV. (METERS)
545000	5237000	24	545500	5237000	101
546000	5237000	85	546500	5237000	119
547000	5237000	137	547500	5237000	128
548000	5237000	134	548500	5237000	116
549000	5237000	115	549500	5237000	113
550000	5237000	110	550500	5237000	64
551000	5237000	61	551500	5237000	70
552000	5237000	75	537000	5237500	67
537500	5237500	73	538000	5237500	61
538500	5237500	0	539000	5237500	0
539500	5237500	0	540000	5237500	0
540500	5237500	0	541000	5237500	0
541500	5237500	0	542000	5237500	0
542500	5237500	0	543000	5237500	0
543500	5237500	0	544000	5237500	0
544500	5237500	0	545000	5237500	122
545500	5237500	113	546000	5237500	98
546500	5237500	119	547000	5237500	128
547500	5237500	131	548000	5237500	134
548500	5237500	110	549000	5237500	122
549500	5237500	125	550000	5237500	115
550500	5237500	82	551000	5237500	70
551500	5237500	82	552000	5237500	88
537000	5238000	43	537500	5238000	37
538000	5238000	0	538500	5238000	0
539000	5238000	0	539500	5238000	0
540000	5238000	0	540500	5238000	0
541000	5238000	0	541500	5238000	0
542000	5238000	0	542500	5238000	0
543000	5238000	0	543500	5238000	0
544000	5238000	0	544500	5238000	67
545000	5238000	122	545500	5238000	129
546000	5238000	98	546500	5238000	110
547000	5238000	122	547500	5238000	125
548000	5238000	122	548500	5238000	107
549000	5238000	116	549500	5238000	116
550000	5238000	76	550500	5238000	89
551000	5238000	91	551500	5238000	85
552000	5238000	101	537000	5238500	34
537500	5238500	6	538000	5238500	0
538500	5238500	0	539000	5238500	0
539500	5238500	0	540000	5238500	0
540500	5238500	0	541000	5238500	0
541500	5238500	0	542000	5238500	0
542500	5238500	30	543000	5238500	67

TABLE B-1.

UTM X (METERS)	UTM Y (METERS)	ELEV. (METERS)	UTM X (METERS)	UTM Y (METERS)	ELEV. (METERS)
543500	5238500	104	544000	5238500	110
544500	5238500	128	545000	5238500	140
545500	5238500	140	546000	5238500	110
546500	5238500	101	547000	5238500	122
547500	5238500	119	548000	5238500	110
548500	5238500	104	549000	5238500	107
549500	5238500	91	550000	5238500	101
550500	5238500	107	551000	5238500	94
551500	5238500	91	552000	5238500	101
537000	5239000	0	537500	5239000	0
538000	5239000	0	538500	5239000	0
539000	5239000	0	539500	5239000	0
540000	5239000	0	540500	5239000	0
541000	5239000	0	541500	5239000	0
542000	5239000	0	542500	5239000	21
543000	5239000	58	543500	5239000	98
544000	5239000	137	544500	5239000	165
545000	5239000	134	545500	5239000	140
546000	5239000	104	546500	5239000	110
547000	5239000	125	547500	5239000	98
548000	5239000	101	548500	5239000	98
549000	5239000	94	549500	5239000	91
550000	5239000	122	550500	5239000	94
551000	5239000	104	551500	5239000	110
552000	5239000	113	537000	5239500	0
537500	5239500	0	538000	5239500	0
538500	5239500	0	539000	5239500	0
539500	5239500	0	540000	5239500	0
540500	5239500	0	541000	5239500	0
541500	5239500	0	542000	5239500	0
542500	5239500	0	543000	5239500	12
543500	5239500	115	544000	5239500	131
544500	5239500	119	545000	5239500	104
545500	5239500	91	546000	5239500	79
546500	5239500	98	547000	5239500	91
547500	5239500	85	548000	5239500	88
548500	5239500	104	549000	5239500	94
549500	5239500	101	550000	5239500	128
550500	5239500	113	551000	5239500	115
551500	5239500	122	552000	5239500	122
537000	5240000	0	537500	5240000	0
538000	5240000	0	538500	5240000	0
539000	5240000	0	539500	5240000	0
540000	5240000	0	540500	5240000	0
541000	5240000	0	541500	5240000	0

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TABLE B-1.

UTM X (METERS)	UTM Y (METERS)	ELEV. (METERS)	UTM X (METERS)	UTM Y (METERS)	ELEV. (METERS)
542000	5240000	0	542500	5240000	0
543000	5240000	0	543500	5240000	113
544000	5240000	83	544500	5240000	49
545000	5240000	59	545500	5240000	75
546000	5240000	73	546500	5240000	67
547000	5240000	67	547500	5240000	73
548000	5240000	82	548500	5240000	101
549000	5240000	91	549500	5240000	99
550000	5240000	104	550500	5240000	110
551000	5240000	115	551500	5240000	134
552000	5240000	122	537000	5240500	0
537500	5240500	0	538000	5240500	0
538500	5240500	0	539000	5240500	0
539500	5240500	0	540000	5240500	0
540500	5240500	0	541000	5240500	0
541500	5240500	0	542000	5240500	0
542500	5240500	0	543000	5240500	0
543500	5240500	24	544000	5240500	43
544500	5240500	21	545000	5240500	67
545500	5240500	73	546000	5240500	67
546500	5240500	79	547000	5240500	79
547500	5240500	73	548000	5240500	67
548500	5240500	85	549000	5240500	85
549500	5240500	94	550000	5240500	91
550500	5240500	113	551000	5240500	125
551500	5240500	134	552000	5240500	131
537000	5241000	0	537500	5241000	0
538000	5241000	0	538500	5241000	0
539000	5241000	0	539500	5241000	0
540000	5241000	0	540500	5241000	0
541000	5241000	0	541500	5241000	0
542000	5241000	0	542500	5241000	0
543000	5241000	0	543500	5241000	0
544000	5241000	0	544500	5241000	0
545000	5241000	0	545500	5241000	61
546000	5241000	55	546500	5241000	49
547000	5241000	34	547500	5241000	70
548000	5241000	43	548500	5241000	61
549000	5241000	91	549500	5241000	98
550000	5241000	98	550500	5241000	104
551000	5241000	134	551500	5241000	134
552000	5241000	149	537000	5241500	0
537500	5241500	0	538000	5241500	0
538500	5241500	0	539000	5241500	0
539500	5241500	0	540000	5241500	0

TABLE B-1.

UTM X (METERS)	UTM Y (METERS)	ELEV. (METERS)	UTM X (METERS)	UTM Y (METERS)	ELEV. (METERS)
540500	5241500	0	541000	5241500	0
541500	5241500	0	542000	5241500	0
542500	5241500	0	543000	5241500	0
543500	5241500	0	544000	5241500	0
544500	5241500	0	545000	5241500	0
545500	5241500	0	546000	5241500	49
546500	5241500	6	547000	5241500	0
547500	5241500	40	548000	5241500	91
548500	5241500	89	549000	5241500	99
549500	5241500	98	550000	5241500	98
550500	5241500	104	551000	5241500	131
551500	5241500	131	552000	5241500	143
537000	5242000	0	537500	5242000	30
538000	5242000	55	538500	5242000	9
539000	5242000	0	539500	5242000	0
540000	5242000	0	540500	5242000	0
541000	5242000	0	541500	5242000	0
542000	5242000	0	542500	5242000	0
543000	5242000	0	543500	5242000	0
544000	5242000	0	544500	5242000	0
545000	5242000	0	545500	5242000	0
546000	5242000	0	546500	5242000	0
547000	5242000	0	547500	5242000	15
548000	5242000	82	548500	5242000	79
549000	5242000	104	549500	5242000	107
550000	5242000	107	550500	5242000	113
551000	5242000	104	551500	5242000	137
552000	5242000	146			

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APPENDIX C

PRELIMINARY SHORTZ AND LONGZ METEOROLOGICAL INPUTS

Table C-1 lists in chronological order the SHORTZ hourly meteorological inputs for the 23 "worst case" 3-hour periods discussed in Section 5.1. Similarly, Table C-2 lists in chronological order the SHORTZ hourly meteorological inputs for the 14 "worst case" 24-hour periods discussed in Section 5.1. The annual wind summary (STAR summary) suggested in Section 5.2 for use with LONGZ is given in Table C-3.

TABLE C-1
SHORTZ 3-HOUR METEOROLOGICAL INPUTS

HOUR (PST)	WIND DIR. (DEG)	WIND SPEED (MPS)	MIXING DEPTH (M)	AMB. TEMP (DEG K)	POT. TEMP (DEG K/M)	STAB CAT.	WIND EXP.	STD DEV. EL ANGLE (RAD)	STD DEV. AZ ANGLE (RAD)
16 FEBRUARY 1981									
20	217	7.60	875	285	.003	D	.10	.0465	.0665
21	217	6.30	875	286	.003	D	.10	.0465	.0665
22	217	5.90	875	286	.003	D	.10	.0465	.0665
17 FEBRUARY 1981									
2	229	5.20	875	285	.003	D	.10	.0465	.0665
3	228	5.10	690	286	.005	D	.15	.0465	.0665
4	229	4.70	690	286	.005	D	.15	.0465	.0665
29 MARCH 1981									
8	224	6.20	875	285	.003	D	.10	.0465	.0665
9	222	6.60	875	284	.003	D	.10	.0465	.0665
10	224	6.90	875	283	.003	D	.10	.0465	.0665
29 MARCH 1981									
12	230	6.50	875	283	.003	D	.10	.0465	.0665
13	231	6.70	875	283	.003	D	.10	.0465	.0665
14	230	6.70	875	283	.003	D	.10	.0465	.0665
30 MARCH 1981									
9	212	4.40	690	280	.005	D	.15	.0465	.0665
10	212	4.70	690	280	.005	D	.15	.0465	.0665
11	213	4.70	690	280	.005	D	.15	.0465	.0665
31 MARCH 1981									
6	185	4.60	690	283	.005	D	.15	.0465	.0665
7	184	4.20	690	283	.005	D	.15	.0465	.0665
8	185	3.70	690	282	.005	D	.15	.0465	.0665
5 APRIL 1981									
17	245	6.70	875	284	.003	D	.10	.0465	.0665
18	247	6.50	875	284	.003	D	.10	.0465	.0665
19	246	6.20	875	284	.003	D	.10	.0465	.0665

TABLE C-1 (Continued)

HOUR (PST)	WIND DIR. (DEG)	WIND SPEED (MPS)	MIXING DEPTH (M)	AMB. TEMP (DEG K)	POT. TEMP (DEG K/M)	STAB CAT.	WIND EXP.	STD DEV. EL ANGLE (RAD)	STD DEV. AZ ANGLE (RAD)
21 APRIL 1981									
13	237	3.50	690	282	.005	D	.15	.0465	.0665
14	237	4.20	690	281	.005	D	.15	.0465	.0665
15	237	4.30	690	281	.005	D	.15	.0465	.0665
22 APRIL 1981									
4	216	4.20	690	286	.005	D	.15	.0465	.0665
5	217	4.80	690	286	.005	D	.15	.0465	.0665
6	216	4.60	690	287	.005	D	.15	.0465	.0665
21 MAY 1981									
7	214	4.20	690	288	.005	D	.15	.0465	.0665
8	214	4.40	690	289	.005	D	.15	.0465	.0665
9	213	4.10	690	287	.005	D	.15	.0465	.0665
30 MAY 1981									
1	235	2.10	250	290	.020	E	.25	.0350	.0501
2	236	2.10	250	295	.020	E	.25	.0350	.0501
3	236	2.40	250	296	.020	E	.25	.0350	.0501
13-14 JUNE 1981									
23	222	2.20	250	284	.020	E	.25	.0350	.0501
24	220	2.10	250	285	.020	E	.25	.0350	.0501
1	222	2.00	250	287	.020	E	.25	.0350	.0501
17 JUNE 1981									
8	223	4.60	690	288	.005	D	.15	.0465	.0665
9	222	4.70	690	288	.005	D	.15	.0465	.0665
10	223	5.00	690	287	.005	D	.15	.0465	.0665
18 JUNE 1981									
15	212	3.60	690	284	.005	D	.15	.0465	.0665
16	211	4.90	690	284	.005	D	.15	.0465	.0665
17	212	5.50	875	283	.003	D	.10	.0465	.0665

TABLE C-1 (Continued)

HOUR (PST)	WIND DIR. (DEG)	WIND SPEED (MPS)	MIXING DEPTH (M)	AMB. TEMP (DEG K)	POT. TEMP (DEG K/M)	STAB CAT.	WIND EXP.	STD DEV. EL ANGLE (RAD)	STD DEV. AZ ANGLE (RAD)
26-27 JULY 1981									
24	36	1.50	125	293	.030	E	.30	.0350	.0501
1	39	2.00	250	296	.020	E	.25	.0350	.0501
2	37	1.90	250	298	.020	E	.25	.0350	.0501
27-28 JULY 1981									
23	234	2.10	250	291	.020	E	.25	.0350	.0501
24	234	2.50	250	295	.020	E	.25	.0350	.0501
1	232	2.50	250	296	.020	E	.25	.0350	.0501
9 AUGUST 1981									
1	52	1.40	125	299	.030	E	.30	.0350	.0501
2	52	1.60	250	300	.020	E	.25	.0350	.0501
3	51	1.70	250	301	.020	E	.25	.0350	.0501
24 AUGUST 1981									
2	227	2.30	250	295	.020	E	.25	.0350	.0501
3	228	2.50	250	296	.020	E	25	.0350	.0501
4	227	2.00	250	297	.020	E	.25	.0350	.0501
25-26 AUGUST 1981									
23	47	2.10	250	288	.020	E	.25	.0350	.0501
24	50	2.40	250	289	.020	E	.25	.0350	.0501
1	49	1.50	125	291	.030	E	.30	.0350	.0501
1 SEPTEMBER 1981									
11	225	5.60	875	290	.020	D	.10	.0465	.0665
12	224	5.00	690	289	.020	D	.15	.0465	.0665
13	224	4.90	690	289	.020	D	.15	.0465	.0665

TABLE C-1 (Continued)

HOUR (PST)	WIND DIR. (DEG)	WIND SPEED (MPS)	MIXING DEPTH (M)	AMB. TEMP (DEG K)	POT. TEMP (DEG K/M)	STAB CAT.	WIND EXP.	STD DEV. EL ANGLE (RAD)	STD DEV. AZ ANGLE (RAD)
				25 SEPTEMBER 1981					
19	57	1.40	125	283	.030	E	.30	.0350	.0501
20	59	1.50	125	283	.030	E	.30	.0350	.0501
21	56	1.80	250	282	.020	E	.25	.0350	.0501
				2 OCTOBER 1981					
19	227	2.50	250	283	.020	E	.25	.0350	.0501
20	225	2.00	250	283	.020	E	.25	.0350	.0501
21	226	2.10	250	283	.020	E	.25	.0350	.0501
				25 DECEMBER 1981					
20	205	2.50	250	277	.020	E	.25	.0350	.0501
21	206	2.10	250	276	.020	E	.25	.0350	.0501
22	208	2.00	250	278	.020	E	.25	.0350	.0501

TABLE C-2

SHORTZ 24-HOUR METEOROLOGICAL INPUTS

HOUR (PST)	WIND DIR. (DEG)	WIND SPEED (MPS)	MIXING DEPTH (M)	AMB. TEMP (DEG K)	POT. TEMP (DEG K/M)	STAB CAT.	WIND EXP.	STD DEV. EL ANGLE (RAD)	STD DEV. AZ ANGLE (RAD)
				23-24 JANUARY 1981					
19	211	2.30	595	281	.010	D	.20	.0465	.0665
20	208	2.60	595	281	.010	D	.20	.0465	.0665
21	194	2.30	595	281	.010	D	.20	.0465	.0665
22	196	2.40	595	281	.010	D	.20	.0465	.0665
23	204	2.30	595	281	.010	D	.20	.0465	.0665
24	206	2.90	595	281	.010	D	.20	.0465	.0665
1	218	3.30	690	281	.005	D	.15	.0465	.0665
2	223	3.30	690	281	.005	D	.15	.0465	.0665
3	228	3.50	690	282	.005	D	.15	.0465	.0665
4	229	3.30	690	282	.005	D	.15	.0465	.0665
5	225	3.30	690	282	.005	D	.15	.0465	.0665
6	229	3.30	690	282	.005	D	.15	.0465	.0665
7	228	2.80	595	281	.010	D	.20	.0465	.0665
8	208	2.20	595	281	.010	D	.20	.0465	.0665
9	209	2.50	595	281	.010	D	.20	.0465	.0665
10	213	2.20	595	281	.010	D	.20	.0465	.0665
11	228	3.00	595	282	.010	D	.20	.0465	.0665
12	224	3.50	690	280	.005	D	.15	.0465	.0665
13	221	3.30	690	280	.005	D	.15	.0465	.0665
14	214	3.60	690	279	.005	D	.15	.0465	.0665
15	223	3.50	690	279	.005	D	.15	.0465	.0665
16	221	3.40	690	279	.005	D	.15	.0465	.0665
17	212	2.10	250	279	.020	E	.25	.0350	.0501
18	182	1.80	250	278	.020	E	.25	.0350	.0501
				16-17 FEBRUARY 1981					
10	209	4.60	690	284	.005	D	.15	.0465	.0665
11	200	4.40	690	284	.005	D	.15	.0465	.0665
12	210	5.50	875	283	.003	D	.10	.0465	.0665
13	221	5.90	875	283	.003	D	.10	.0465	.0665
14	221	6.30	875	283	.003	D	.10	.0465	.0665
15	216	6.90	875	283	.003	D	.10	.0465	.0665
16	219	6.70	875	283	.003	D	.10	.0465	.0665
17	213	6.70	875	283	.003	D	.10	.0465	.0665
18	211	7.10	875	283	.003	D	.10	.0465	.0665
19	214	8.20	875	285	.003	D	.10	.0465	.0665
20	217	7.60	875	285	.003	D	.10	.0465	.0665
21	217	6.30	875	286	.003	D	.10	.0465	.0665
22	217	5.90	875	286	.003	D	.10	.0465	.0665
23	222	5.70	875	286	.003	D	.10	.0465	.0665
24	226	4.90	690	285	.005	D	.15	.0465	.0665

TABLE C-2 (Continued)

HOUR (PST)	WIND DIR. (DEG)	WIND SPEED (MPS)	MIXING DEPTH (M)	AMB. TEMP (DEG K)	POT. TEMP (DEG K/M)	STAB CAT.	WIND EXP.	STD DEV. EL ANGLE (RAD)	STD DEV. AZ ANGLE (RAD)
1	234	5.10	690	285	.005	D	.15	.0465	.0665
2	229	5.20	875	285	.003	D	.10	.0465	.0665
3	228	5.10	690	286	.005	D	.15	.0465	.0665
4	229	4.70	690	286	.005	D	.15	.0465	.0665
5	225	4.50	690	287	.005	D	.15	.0465	.0665
6	212	3.70	690	286	.005	D	.15	.0465	.0665
7	214	3.70	690	285	.005	D	.15	.0465	.0665
8	219	3.80	690	284	.005	D	.15	.0465	.0665
9	212	4.10	690	283	.005	D	.15	.0465	.0665
29-30 MARCH 1981									
6	224	7.80	875	285	.003	D	.10	.0465	.0665
7	217	7.00	875	285	.003	D	.10	.0465	.0665
8	224	6.20	875	285	.003	D	.10	.0465	.0665
9	222	6.50	875	287	.003	D	.10	.0465	.0665
10	224	6.90	875	283	.003	D	.10	.0465	.0665
11	236	6.60	875	283	.003	D	.10	.0465	.0665
12	230	6.50	875	283	.003	D	.10	.0465	.0665
13	231	6.70	875	283	.003	D	.10	.0465	.0665
14	230	6.70	875	283	.003	D	.10	.0465	.0665
15	227	6.70	875	282	.003	D	.10	.0465	.0665
16	229	7.00	875	281	.003	D	.10	.0465	.0665
17	224	6.30	875	281	.003	D	.10	.0465	.0665
18	221	6.50	875	281	.003	D	.10	.0465	.0665
19	218	6.90	875	282	.003	D	.10	.0465	.0665
20	221	6.30	875	283	.003	D	.10	.0465	.0665
21	225	6.00	875	281	.003	D	.10	.0465	.0665
22	234	5.30	875	280	.003	D	.10	.0465	.0665
23	238	5.60	875	280	.003	D	.10	.0465	.0665
24	234	5.50	875	280	.003	D	.10	.0465	.0665
1	230	5.40	875	280	.003	D	.10	.0465	.0665
2	229	5.30	875	281	.003	D	.10	.0465	.0665
3	223	5.20	875	281	.003	D	.10	.0465	.0665
4	220	5.60	875	281	.003	D	.10	.0465	.0665
5	224	6.10	875	281	.003	D	.10	.0465	.0665
30-31 MARCH 1981									
6	220	5.80	875	281	.003	D	.10	.0465	.0665
7	214	4.50	690	281	.005	D	.15	.0465	.0665
8	217	4.40	690	281	.005	D	.15	.0465	.0665
9	212	4.40	690	280	.005	D	.15	.0465	.0665
10	212	4.70	690	280	.005	D	.15	.0465	.0665

TABLE C-2 (Continued)

HOUR (PST)	WIND DIR. (DEG)	WIND SPEED (MPS)	MIXING DEPTH (M)	AMB. TEMP (DEG K)	POT. TEMP (DEG K/M)	STAB CAT.	WIND EXP.	STD DEV. EL ANGLE (RAD)	STD DEV. AZ ANGLE (RAD)
11	213	4.70	690	280	.005	D	.15	.0465	.0665
12	210	4.90	690	280	.005	D	.15	.0465	.0665
13	212	5.30	1000	280	0.000	C	.10	.0735	.1051
14	218	5.50	875	279	.003	D	.10	.0465	.0665
15	212	5.40	1000	279	0.000	C	.10	.0735	.1051
16	205	5.70	875	279	.003	D	.10	.0465	.0665
17	194	5.20	875	279	.003	D	.10	.0465	.0665
18	203	4.70	690	279	.005	D	.15	.0465	.0665
19	199	4.70	690	279	.005	D	.15	.0465	.0665
20	208	4.20	690	279	.005	D	.15	.0465	.0665
21	203	4.20	440	279	.015	E	.20	.0350	.0501
22	203	4.70	690	279	.005	D	.15	.0465	.0665
23	187	4.20	690	279	.005	D	.15	.0465	.0665
24	195	5.00	690	279	.005	D	.15	.0465	.0665
1	201	4.60	690	280	.005	D	.15	.0465	.0665
2	199	5.00	690	280	.005	D	.15	.0465	.0665
3	202	4.30	690	281	.005	D	.15	.0465	.0665
4	208	4.70	690	281	.005	D	.15	.0465	.0665
5	194	4.70	690	282	.005	D	.15	.0465	.0665
					8-9 APRIL 1981				
15	221	5.30	875	280	.003	D	.10	.0465	.0665
16	222	5.00	690	280	.005	D	.15	.0465	.0665
17	216	5.60	875	279	.003	D	.10	.0465	.0665
18	224	5.60	875	279	.003	D	.10	.0465	.0665
19	230	5.40	875	279	.003	D	.10	.0465	.0665
20	228	5.80	875	279	.003	D	.10	.0465	.0665
21	224	5.20	875	279	.003	D	.10	.0465	.0665
22	218	4.80	690	279	.005	D	.15	.0465	.0665
23	221	4.90	690	279	.005	D	.15	.0465	.0665
24	221	5.10	690	280	.005	D	.15	.0465	.0665
1	286	4.20	690	280	.005	D	.15	.0465	.0665
2	212	5.00	690	280	.005	D	.15	.0465	.0665
3	211	5.60	875	281	.003	D	.10	.0465	.0665
4	214	5.70	875	281	.003	D	.10	.0465	.0665
5	218	5.60	875	283	.003	D	.10	.0465	.0665
6	214	5.40	875	282	.003	D	.10	.0465	.0665
7	217	4.70	690	281	.005	D	.15	.0465	.0665
8	222	4.60	690	280	.005	D	.15	.0465	.0665
9	221	5.80	875	280	.003	D	.10	.0465	.0665
10	219	5.90	875	280	.003	D	.10	.0465	.0665
11	211	6.20	1000	280	0.000	B	.10	.1080	.1544
12	229	4.60	940	279	0.000	C	.10	.0735	.1051

TABLE C-2 (Continued)

HOUR (PST)	WIND DIR. (DEG)	WIND SPEED (MPS)	MIXING DEPTH (M)	AMB. TEMP (DEG K)	POT. TEMP (DEG K/M)	STAB CAT.	WIND EXP.	STD DEV. EL ANGLE (RAD)	STD DEV. AZ ANGLE (RAD)
13	230	4.50	940	278	0.000	C	.10	.0735	.1051
14	226	4.60	940	278	0.000	C	.10	.0735	.1051
21-22 APRIL 1981									
16	231	4.50	690	281	.005	D	.15	.0465	.0665
17	229	3.80	690	280	.005	D	.15	.0465	.0665
18	212	3.50	690	280	.005	D	.15	.0465	.0665
19	218	3.40	690	280	.005	D	.15	.0465	.0665
20	215	4.10	690	280	.005	D	.15	.0465	.0665
21	211	3.80	440	280	.015	E	.20	.0350	.0501
22	221	3.00	250	280	.020	E	.25	.0350	.0501
23	234	2.70	595	281	.010	D	.20	.0465	.0665
24	229	2.80	595	283	.010	D	.20	.0465	.0665
1	219	3.60	690	284	.005	D	.15	.0465	.0665
2	215	3.70	690	285	.005	D	.15	.0465	.0665
3	215	4.00	690	285	.005	D	.15	.0465	.0665
4	216	4.20	690	286	.005	D	.15	.0465	.0665
5	217	4.80	690	286	.005	D	.15	.0465	.0665
6	216	4.60	690	287	.005	D	.15	.0465	.0665
7	219	4.50	690	287	.005	D	.15	.0465	.0665
8	220	4.40	690	287	.005	D	.15	.0465	.0665
9	218	5.20	875	286	.003	D	.10	.0465	.0665
10	228	4.60	690	285	.005	D	.15	.0465	.0665
11	228	5.40	875	285	.003	D	.10	.0465	.0665
12	226	5.70	875	285	.003	D	.10	.0465	.0665
13	226	5.20	1000	285	0.000	C	.10	.0735	.1051
14	228	4.30	940	284	0.000	C	.10	.0735	.1051
15	231	4.10	690	284	.005	D	.15	.0465	.0665
1-2 MAY 1981									
11	224	4.00	940	288	0.000	C	.10	.0735	.1051
12	209	4.20	690	287	.005	D	.15	.0465	.0665
13	214	4.70	690	286	.005	D	.15	.0465	.0665
14	205	4.30	690	285	.005	D	.15	.0465	.0665
15	214	4.40	940	284	0.000	C	.10	.0735	.1051
16	220	4.50	690	283	.005	D	.15	.0465	.0665
17	216	4.00	690	282	.005	D	.15	.0465	.0665
18	248	3.20	690	281	.005	D	.15	.0465	.0665
19	237	3.70	440	281	.015	E	.20	.0350	.0501
20	222	3.80	440	280	.015	E	.20	.0350	.0501
21	227	3.40	440	280	.015	E	.20	.0350	.0501
22	232	3.20	440	281	.015	E	.20	.0350	.0501

TABLE C-2 (Continued)

HOUR (PST)	WIND DIR. (DEG)	WIND SPEED (MPS)	MIXING DEPTH (M)	AMB. TEMP (DEG K)	POT. TEMP (DEG K/M)	STAB CAT.	WIND EXP.	STD DEV. EL ANGLE (RAD)	STD DEV. AZ ANGLE (RAD)
23	213	3.80	440	281	.015	E	.20	.0350	.0501
24	208	3.60	440	283	.015	E	.20	.0350	.0501
1	211	3.90	690	285	.005	D	.15	.0465	.0665
2	216	4.00	690	284	.005	D	.15	.0465	.0665
3	212	3.80	690	284	.005	D	.15	.0465	.0665
4	213	3.90	690	284	.005	D	.15	.0465	.0665
5	209	3.90	690	284	.005	D	.15	.0465	.0665
6	206	4.10	690	284	.005	D	.15	.0465	.0665
7	215	3.90	690	285	.005	D	.15	.0465	.0665
8	213	4.90	690	285	.005	D	.15	.0465	.0665
9	219	5.20	1000	285	0.000	B	.10	.1080	.1544
10	222	5.10	690	284	.005	D	.15	.0465	.0665
20-21 MAY 1981									
3	230	1.70	595	284	.010	D	.20	.0465	.0665
4	227	1.90	595	285	.010	D	.20	.0465	.0665
5	223	2.30	595	285	.010	D	.20	.0465	.0665
6	222	2.60	595	285	.010	D	.20	.0465	.0665
7	222	2.50	595	286	.010	D	.20	.0465	.0665
8	217	2.40	595	287	.010	D	.20	.0465	.0665
9	233	2.60	595	287	.010	D	.20	.0465	.0665
10	233	2.60	595	286	.010	D	.20	.0465	.0665
11	240	2.60	595	286	.010	D	.20	.0465	.0665
12	243	2.50	595	286	.010	D	.20	.0465	.0665
13	242	2.40	595	286	.010	D	.20	.0465	.0665
14	232	2.80	595	285	.010	D	.20	.0465	.0665
15	231	3.30	690	285	.005	D	.15	.0465	.0665
16	239	3.00	595	285	.010	D	.20	.0465	.0665
17	245	3.40	690	284	.005	D	.15	.0465	.0665
18	251	3.50	690	284	.005	D	.15	.0465	.0665
19	243	3.30	690	284	.005	D	.15	.0465	.0665
20	241	3.40	440	284	.015	E	.20	.0350	.0501
21	242	3.80	440	284	.015	E	.20	.0350	.0501
22	237	3.50	690	284	.005	D	.15	.0465	.0665
23	239	4.00	690	284	.005	D	.15	.0465	.0665
24	237	2.80	690	284	.005	D	.20	.0465	.0665
1	234	2.80	690	285	.005	D	.20	.0465	.0665
2	235	3.70	690	285	.005	D	.15	.0465	.0665
25 MAY 1981									
1	234	2.00	595	289	.010	D	.20	.0465	.0665
2	251	1.70	595	290	.010	D	.20	.0465	.0665

TABLE C-2 (Continued)

HOUR (PST)	WIND DIR. (DEG)	WIND SPEED (MPS)	MIXING DEPTH (M)	AMB. TEMP (DEG K)	POT. TEMP (DEG K/M)	STAB CAT.	WIND EXP.	STD DEV. EL ANGLE (RAD)	STD DEV. AZ ANGLE (RAD)
3	247	1.70	250	290	.020	E	.25	.0350	.0501
4	233	1.80	595	290	.010	D	.20	.0465	.0665
5	228	2.00	595	290	.010	D	.20	.0465	.0665
6	229	2.10	940	291	0.000	C	.15	.0735	.1051
7	231	2.70	595	290	.010	D	.20	.0465	.0665
8	237	3.30	690	290	.005	D	.15	.0465	.0665
9	236	3.20	690	289	.005	D	.15	.0465	.0665
10	244	3.80	690	289	.005	D	.15	.0465	.0665
11	249	4.40	690	288	.005	D	.15	.0465	.0665
12	234	4.90	690	288	.005	D	.15	.0465	.0665
13	239	4.20	690	286	.005	D	.15	.0465	.0665
14	234	4.00	690	286	.005	D	.15	.0465	.0665
15	243	3.80	690	286	.005	D	.15	.0465	.0665
16	247	4.40	690	286	.005	D	.15	.0465	.0665
17	250	4.20	690	286	.005	D	.15	.0465	.0665
18	245	3.30	690	286	.005	D	.15	.0465	.0665
19	248	2.90	595	286	.010	D	.20	.0465	.0665
20	236	2.30	595	286	.010	D	.20	.0465	.0665
21	238	2.30	595	286	.010	D	.20	.0465	.0665
22	211	1.90	595	286	.010	D	.20	.0465	.0665
23	204	1.80	595	286	.010	D	.20	.0465	.0665
24	230	1.60	595	286	.010	D	.20	.0465	.0665
5-6 JUNE 1981									
19	244	3.30	690	285	.005	D	.15	.0465	.0665
20	227	3.50	690	285	.005	D	.15	.0465	.0665
21	237	3.50	690	285	.005	D	.15	.0465	.0665
22	210	4.50	690	286	.005	D	.15	.0465	.0665
23	227	4.50	690	286	.005	D	.15	.0465	.0665
24	231	4.20	690	287	.005	D	.15	.0465	.0665
1	237	4.60	690	288	.005	D	.15	.0465	.0665
2	237	4.00	690	289	.005	D	.15	.0465	.0665
3	223	3.90	690	292	.005	D	.15	.0465	.0665
4	208	2.90	595	293	.010	D	.20	.0465	.0665
5	193	1.90	595	291	.010	D	.20	.0465	.0665
6	208	2.90	595	290	.010	D	.20	.0465	.0665
7	219	3.40	690	289	.005	D	.15	.0465	.0665
8	233	3.20	690	289	.005	D	.15	.0465	.0665
9	228	4.20	690	290	.005	D	.15	.0465	.0665
10	219	4.20	690	288	.005	D	.15	.0465	.0665
11	221	3.80	690	288	.005	D	.15	.0465	.0665
12	229	3.50	690	288	.005	D	.15	.0465	.0665
13	232	3.30	940	286	0.000	B	.10	.1080	.1544

TABLE C-2 (Continued)

HOUR (PST)	WIND DIR. (DEG)	WIND SPEED (MPS)	MIXING DEPTH (M)	AMB. TEMP (DEG K)	POT. TEMP (DEG K/M)	STAB CAT.	WIND EXP.	STD DEV. EL ANGLE (RAD)	STD DEV. AZ ANGLE (RAD)
14	237	3.30	690	286	.005	D	.15	.0465	.0665
15	238	3.60	940	284	0.000	B	.10	.1080	.1544
16	241	3.10	940	284	0.000	B	.10	.1080	.1544
17	235	2.90	940	283	0.000	B	.10	.1080	.1544
18	249	2.80	940	283	0.000	C	.15	.0735	.1051
6-7 JULY 1981									
23	221	3.40	690	284	.005	D	.15	.0465	.0665
24	210	3.40	690	285	.005	D	.15	.0465	.0665
1	216	3.10	595	286	.010	D	.15	.0465	.0665
2	222	3.20	690	286	.005	D	.15	.0465	.0665
3	226	3.80	690	286	.005	D	.15	.0465	.0665
4	226	4.00	690	289	.005	D	.15	.0465	.0665
5	224	4.20	690	289	.005	D	.15	.0465	.0665
6	223	4.50	690	289	.005	D	.15	.0465	.0665
7	217	5.70	875	289	.003	D	.10	.0465	.0665
8	220	5.90	875	286	.003	D	.10	.0465	.0665
9	223	6.70	875	288	.003	D	.10	.0465	.0665
10	227	6.40	875	288	.003	D	.10	.0465	.0665
11	228	6.40	1000	287	0.000	C	.10	.0735	.1051
12	226	6.30	1000	286	0.000	B	.10	.1080	.1544
13	233	6.00	1000	285	0.000	B	.10	.1080	.1544
14	225	6.30	1000	284	0.000	C	.10	.0735	.1051
15	227	5.50	1000	283	0.000	B	.10	.1080	.1544
16	239	5.50	1000	282	0.000	B	.10	.1080	.1544
17	236	5.20	1000	283	0.000	C	.10	.0735	.1051
18	239	5.50	1000	283	0.000	C	.10	.0735	.1051
19	234	4.30	690	283	.005	D	.15	.0465	.0665
20	232	4.00	440	283	.015	E	.20	.0350	.0501
21	229	3.90	690	283	.005	D	.15	.0465	.0665
22	227	3.90	690	283	.005	D	.15	.0465	.0665
21-22 JULY 1981									
7	240	2.30	595	293	.010	D	.20	.0465	.0665
8	241	2.00	595	292	.010	D	.20	.0465	.0665
9	243	2.10	595	291	.010	D	.20	.0465	.0665
10	258	2.00	595	290	.010	D	.20	.0465	.0665
11	258	1.30	500	290	.015	D	.25	.0465	.0665
12	251	2.50	595	289	.010	D	.20	.0465	.0665
13	223	3.20	690	289	.005	D	.15	.0465	.0665
14	251	3.70	690	288	.005	D	.15	.0465	.0665
15	257	3.50	690	288	.005	D	.15	.0465	.0665

TABLE C-2 (Continued)

HOUR (PST)	WIND DIR. (DEG)	WIND SPEED (MPS)	MIXING DEPTH (M)	AMB. TEMP (DEG K)	POT. TEMP (DEG K/M)	STAB CAT.	WIND EXP.	STD DEV. EL ANGLE (RAD)	STD DEV. AZ ANGLE (RAD)
16	247	3.10	595	288	.010	D	.15	.0465	.0665
17	250	3.10	595	288	.010	D	.15	.0465	.0665
18	254	3.20	690	287	.005	D	.15	.0465	.0665
19	252	3.00	595	286	.010	D	.20	.0465	.0665
20	244	2.60	595	287	.010	D	.20	.0465	.0665
21	242	2.60	595	286	.010	D	.20	.0465	.0665
22	255	2.50	595	287	.010	D	.20	.0465	.0665
23	259	2.80	595	288	.010	D	.20	.0465	.0665
24	246	2.50	595	288	.010	D	.20	.0465	.0665
1	235	2.20	595	288	.010	D	.20	.0465	.0665
2	223	2.10	250	289	.020	E	.25	.0350	.0501
3	231	1.90	595	290	.010	D	.20	.0465	.0665
4	240	1.90	250	291	.020	E	.25	.0350	.0501
5	244	1.70	250	292	.020	E	.25	.0350	.0501
6	237	1.90	940	291	0.000	C	.15	.0735	.1051
29-30 OCTOBER 1981									
4	218	2.30	595	286	.010	D	.20	.0465	.0665
5	210	2.20	250	286	.020	E	.25	.0350	.0501
6	194	2.40	595	286	.010	D	.20	.0465	.0665
7	194	2.00	595	284	.010	D	.20	.0465	.0665
8	184	2.10	595	284	.010	D	.20	.0465	.0665
9	193	1.90	595	283	.010	D	.20	.0465	.0665
10	213	2.40	595	282	.010	D	.20	.0465	.0665
11	213	3.20	690	283	.005	D	.15	.0465	.0665
12	209	3.80	690	283	.005	D	.15	.0465	.0665
13	209	3.80	690	282	.005	D	.15	.0465	.0665
14	218	3.90	940	281	0.000	C	.10	.0735	.1051
15	214	3.50	940	282	0.000	C	.10	.0735	.1051
16	210	3.40	690	282	.005	D	.15	.0465	.0665
17	209	3.40	690	282	.005	D	.15	.0465	.0665
18	201	2.90	595	281	.010	D	.20	.0465	.0665
19	200	2.60	595	281	.010	D	.20	.0465	.0665
20	213	2.90	595	281	.010	D	.20	.0465	.0665
21	203	2.80	595	281	.010	D	.20	.0465	.0665
22	192	2.20	595	280	.010	D	.20	.0465	.0665
23	190	2.10	595	280	.010	D	.20	.0465	.0665
24	213	1.50	500	281	.015	D	.25	.0465	.0665
1	211	2.10	250	281	.020	E	.25	.0350	.0501
2	204	2.10	595	283	.010	D	.20	.0465	.0665
3	205	1.70	595	283	.010	D	.20	.0465	.0665

TABLE C-2 (Continued)

HOUR (PST)	WIND DIR. (DEG)	WIND SPEED (MPS)	MIXING DEPTH (M)	AMB. TEMP (DEG K)	POT. TEMP (DEG K/M)	STAB CAT.	WIND EXP.	STD DEV. EL ANGLE (RAD)	STD DEV. AZ ANGLE (RAD)
9-10 DECEMBER 1981									
22	204	4.30	440	280	.015	E	.20	.0350	.0501
23	214	5.50	440	279	.015	E	.15	.0350	.0501
24	214	5.40	875	280	.003	D	.10	.0465	.0665
1	206	5.50	875	280	.003	D	.10	.0465	.0665
2	191	5.00	440	281	.015	E	.20	.0350	.0501
3	192	5.90	440	282	.015	E	.15	.0350	.0501
4	195	5.80	875	282	.003	D	.10	.0465	.0665
5	188	4.70	690	283	.005	D	.15	.0465	.0665
6	192	5.20	875	284	.003	D	.10	.0465	.0665
7	195	5.90	875	284	.003	D	.10	.0465	.0665
8	191	5.20	875	284	.003	D	.10	.0465	.0665
9	188	5.00	690	284	.005	D	.15	.0465	.0665
10	209	3.80	690	284	.005	D	.15	.0465	.0665
11	197	4.00	690	283	.005	D	.15	.0465	.0665
12	191	5.10	690	283	.005	D	.15	.0465	.0665
13	200	4.70	690	284	.005	D	.15	.0465	.0665
14	203	5.30	875	283	.003	D	.10	.0465	.0665
15	207	4.40	690	283	.005	D	.15	.0465	.0665
16	210	4.10	690	282	.005	D	.15	.0465	.0665
17	206	4.10	690	281	.005	D	.15	.0465	.0665
18	216	3.40	690	281	.005	D	.15	.0465	.0665
19	204	3.00	595	280	.010	D	.20	.0465	.0665
20	208	3.60	690	280	.005	D	.15	.0465	.0665
21	214	3.40	690	280	.005	D	.15	.0465	.0665

TABLE C-3

1972 ANNUAL JOINT FREQUENCY OF OCCURRENCE AT THE PSAPCA N26th & PEARL SITE OF WIND-SPEED AND WIND-DIRECTION CATEGORIES, CLASSIFIED ACCORDING TO THE PASQUILL STABILITY CATEGORIES

STABILITY CATEGORY A

DIRECTION (SECTOR)	WIND SPEED (M/SEC) 0-1.5	1.6-3.0	TOTAL
N	.0000	.0000	.0000
NNE	.0000	.0005	.0005
NE	.0006	.0002	.0009
ENE	.0004	.0000	.0004
E	.0000	.0000	.0000
ESE	.0000	.0000	.0000
SE	.0000	.0000	.0000
SSE	.0000	.0000	.0000
S	.0000	.0000	.0000
SSW	.0001	.0000	.0001
SW	.0000	.0002	.0002
WSW	.0001	.0002	.0004
W	.0004	.0002	.0006
WNW	.0002	.0001	.0004
NW	.0002	.0000	.0002
NNW	.0005	.0000	.0005
TOTAL	.0026	.0016	.0042

STABILITY CATEGORY B

DIRECTION (SECTOR)	WIND SPEED (M/SEC) 0-1.5	1.6-3.0	3.1-5.1	TOTAL
N	.0015	.0017	.0016	.0048
NNE	.0042	.0050	.0033	.0126
NE	.0052	.0049	.0030	.0131
ENE	.0024	.0012	.0000	.0036
E	.0006	.0000	.0000	.0006
ESE	.0001	.0000	.0000	.0001
SE	.0000	.0000	.0000	.0000
SSE	.0004	.0001	.0000	.0005
S	.0005	.0001	.0000	.0006
SSW	.0010	.0000	.0000	.0010
SW	.0015	.0010	.0016	.0040
WSW	.0037	.0044	.0021	.0102
W	.0051	.0023	.0005	.0085
WNW	.0028	.0005	.0000	.0033
NW	.0032	.0002	.0000	.0035
NNW	.0023	.0002	.0000	.0026
TOTAL	.0346	.0224	.0121	.0691

STABILITY CATEGORY C

DIRECTION (SECTOR)	WIND SPEED (M/SEC) 0-1.5	1.6-3.0	3.1-5.1	5.2-8.2	8.3-10.8	>10.8	TOTAL
N	.0032	.0020	.0037	.0006	.0000	.0000	.0095
NNE	.0025	.0042	.0131	.0032	.0000	.0000	.0230
NE	.0046	.0059	.0079	.0007	.0000	.0000	.0201
ENE	.0020	.0017	.0002	.0000	.0000	.0000	.0039
E	.0010	.0001	.0001	.0000	.0000	.0000	.0012
ESE	.0004	.0001	.0000	.0000	.0000	.0000	.0005
SE	.0005	.0000	.0000	.0000	.0000	.0000	.0005
SSE	.0011	.0004	.0001	.0000	.0000	.0000	.0016
S	.0012	.0010	.0004	.0000	.0000	.0000	.0026
SSW	.0012	.0010	.0011	.0001	.0000	.0000	.0034
SW	.0030	.0033	.0044	.0004	.0000	.0000	.0111
WSW	.0027	.0048	.0041	.0001	.0000	.0000	.0117
W	.0024	.0015	.0005	.0000	.0000	.0000	.0043
WNW	.0016	.0006	.0001	.0000	.0000	.0000	.0023
NW	.0011	.0004	.0000	.0000	.0000	.0000	.0015
NNW	.0012	.0001	.0001	.0000	.0000	.0000	.0015
TOTAL	.0298	.0281	.0359	.0052	.0000	.0000	.0989

STABILITY CATEGORY D

DIRECTION (SECTOR)	WIND SPEED (M/SEC) 0-1.5	1.6-3.0	3.1-5.1	5.2-8.2	8.3-10.8	>10.8	TOTAL
N	.0071	.0052	.0020	.0011	.0000	.0000	.0154
NNE	.0093	.0133	.0137	.0139	.0016	.0001	.0519
NE	.0117	.0133	.0122	.0103	.0004	.0000	.0479
ENE	.0062	.0031	.0016	.0014	.0007	.0000	.0130
E	.0036	.0031	.0007	.0007	.0000	.0000	.0081
ESE	.0056	.0022	.0015	.0001	.0000	.0000	.0094
SE	.0045	.0018	.0009	.0002	.0000	.0000	.0075
SSE	.0115	.0050	.0023	.0007	.0000	.0000	.0196
S	.0164	.0148	.0083	.0050	.0009	.0000	.0454
SSW	.0136	.0193	.0320	.0296	.0039	.0005	.0997
SW	.0133	.0262	.0393	.0329	.0038	.0005	.1160
WSW	.0122	.0204	.0173	.0144	.0041	.0010	.0691
W	.0113	.0084	.0021	.0006	.0000	.0000	.0223
WNW	.0053	.0011	.0000	.0000	.0000	.0000	.0064
NW	.0032	.0007	.0003	.0000	.0000	.0000	.0043
NNW	.0029	.0007	.0001	.0001	.0000	.0000	.0039
TOTAL	.1373	.1393	.1344	.1112	.0154	.0021	.5394

STABILITY CATEGORY E

DIRECTION (SECTOR)	WIND SPEED (M/SEC) 0-1.5	1.6-3.0	3.1-5.1	TOTAL	ANNUAL WIND DIRECTION DISTRIBUTION
N	.0113	.0043	.0005	.0161	.0458
NNE	.0152	.0196	.0078	.0426	.1305
NE	.0181	.0198	.0087	.0467	.1287
ENE	.0088	.0045	.0009	.0142	.0351
E	.0046	.0026	.0004	.0076	.0175
ESE	.0045	.0009	.0004	.0057	.0157
SE	.0046	.0014	.0001	.0061	.0141
SSE	.0149	.0059	.0010	.0218	.0436
S	.0126	.0127	.0012	.0265	.0751
SSW	.0125	.0116	.0025	.0266	.1308
SW	.0140	.0131	.0020	.0290	.1604
WSW	.0077	.0087	.0026	.0190	.1104
W	.0066	.0017	.0002	.0096	.0443
WNW	.0055	.0004	.0000	.0059	.0183
NW	.0051	.0004	.0000	.0055	.0147
NNW	.0050	.0007	.0000	.0056	.0150
TOTAL	.1520	.1081	.0282	.2894	